CIPC and 2,6-DIPN Sprout Suppression of Stored Potatoes

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ABSTRACT

A five-year storage season study using small-scale bins was undertaken to determine the effectiveness of 2,6-diisopropylnaphthlene (2,6-DIPN) in combination with isopropyl-N-(3-chlorophenyl)carbamate (CIPC) for sprout suppression of stored potatoes (*Solanum tuberosum* L.). The study environment simulated a commercial operation and the storage bins held up to 4,500 kg of tubers. Russet Burbank potatoes were tested for four storage seasons, and for one season the bin space was split between Ranger Russet and Snowden potatoes. Sprout suppression was measured as percent acceptable for fresh pack (%AFP), defined as sprouts ≤ 3 mm in length. When 2,6-DIPN was used alone at 8.3 mg kg^{-1} fw, it only provided short-term sprout suppression. Sprout suppression responses for the two chemicals were similar for Russet Burbank, Snowden and Ranger Russet. When 2,6-DIPN was used in combination with CIPC, a significant increase in sprout suppression was observed. In addition, when the two chemicals were used in combination, the amount of CIPC could be reduced by as much as 50% while still maintaining equal or better sprout suppression as compared to CIPC alone. For overall long-term sprout suppression, the best treatment was a combination of CIPC and 2,6-DIPN, each at 16.6 mg kg^{-1}.

RESUMEN

Con el objeto de determinar la efectividad del 2,6-diisopropilnaftaleno (2,6-DIPN) en combinación con el isopropil-N-(3 clorofenil) carbamato (CIPC) para la supresión del brotamiento en papa (*Solanum tuberosum* L.) almacenada, se llevó a cabo un estudio durante cinco periodos de almacenamiento. El estudio se realizó en un ambiente similar al utilizado en operaciones comerciales, en recipientes pequeños con capacidad de hasta 4.500 kg de tubérculos. Se probaron papas Russet Burbank por cuatro períodos de almacenamiento. Durante un período se colocaron papas Ranger Russet y Snowdon en el mismo recipiente. La supresión del brotamiento se midió como porcentaje aceptable para empaque en fresco, considerándose como aceptable brotes de 3mm de largo. Cuando se utilizó únicamente 2,6-DIPN a razón de 8.3 mg kg^{-1} de peso fresco, se produjo sólo una supresión de brotamiento de muy corta duración. Las respuestas de supresión de brotamiento fueron similares para Russet Burbank, Snowden y Ranger Russet. Cuando se utilizó 2,6-DIPN en combinación con CIPC se observó un significativo incremento en la supresión del brotamiento. Adicionalmente, cuando los dos productos químicos se usaron en combinación , la cantidad de CIPC pudo reducirse hasta en un 50%, manteniéndose una igual o mejor supresión de brotamiento en comparación que cuando se usó solamente CPC. Para una supresión completa, el mejor tratamiento fue una combinación de CIPC y 2,6-DIPN, a razón de 16.6 mg kg^{-1} cada uno.

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ADDITIONAL KEY WORDS: Russet Burbank, Ranger Russet, Snowden.

INTRODUCTION

CIPC is widely used in North America and Europe for in-storage potato sprout suppression. The ability to prevent

Abbreviations: Isopropyl-N-(3-chlorophenyl) carbamate (CIPC), 2,6-diisopropylnapthalene (2,6-DIPN), dimethylnaphthalene (DMN), Percent acceptable for fresh pack (%AFP), mg of active ingredient kg^{-1} fresh potato (mg kg^{-1}).

sprouting has allowed the french-fry and potato chip processing markets to flourish by maintaining a long-term raw product supply. Recently the U.S. residue tolerance (40 CFR §180.181) for CIPC was reduced from 50 to 30 mg kg^{-1} or 30 ppm as defined by the U.S. Environmental Protection Agency. Because of the regulatory concern of CIPC on potato and the need to maintain long-term storage of raw product for the processing industry, alternative sprout inhibitors have been evaluated.

Vaughn and Spencer (1991; 1993) found that volatile monoterpenes suppress sprouting by killing meristematic tissue and that a number of aldehydes can prevent sprouting. Everst-Todd (1986) patented the use of substituted naphthalenes, including dimethylnaphthalene (DMN), as sprout inhibitors. Beveridge et al. (1981a) assessed the effects of benzothiazole, DMN, and carvone as sprout inhibitors and found 1,4-dimethylnaphthalene dust formulations suppressed sprouting for 12 wk when used at 100 mg kg^{-1}. Beveridge et al. (1981b) also found that DMN could effectively suppress sprouting, but that the level of suppression was not adequate for long-term storage and repeat applications were necessary. Kalt et al. (1999) evaluated CIPC, carvone, ethylene, and DMN for sprout suppression and found that after a 25-wk storage period the best sprout suppression was with CIPC and the least with DMN.

Lewis et al. (1997) examined mixed isomers of DMN and diisopropylnaphthalene (DIPN) and compared these to CIPC for sprout control. The DMN mixture contained 10 different isomers and the DIPN mixture consisted of at least six isomers. The substituted naphthalenes were applied as thermal aerosol fogs to Russet Burbank potatoes. Their results showed that two 300 mg kg^{-1} DIPN applications were as effective as a single 22 mg kg^{-1} CIPC application over a 10-month storage period and DMN suppressed tuber sprouting, but DMN was not as efficient as DIPN. A positive synergistic effect on potato sprout suppression was found when substituted naphthalenes were used with CIPC (Riggle and Schafer 1997).

The objective of this research was to examine the long-term effect of 2,6-DIPN on potato sprouting when compared to CIPC and when used with CIPC.

MATERIALS AND METHODS

General

The research encompassed five storage seasons (Table 1). 'Russet Burbank' potatoes were used in all storage seasons except 1998/99 when 'Snowden' and 'Ranger Russet' (split bins) potatoes were studied. Potatoes were grown at Parma, Idaho. Standard agronomic practices were followed for preparing seed, seed treatment, planting, fertility, disease con-

TABLE 1—*Treatment combinations and cultivars used in this study. The Russet Burbank cultivar was tested in all years except 1998/1999, when Ranger Russet and Snowden cultivars were tested in split-bins.*

Treatment Year(s)	Treatment[a]	Date(s) Treated[b]
1996/1997	UTC[c]; CIPC 16.6 mg kg^{-1}; CIPC 16.6 mg kg^{-1} plus[d] 2,6-DIPN 16.6 mg kg^{-1}; CIPC 11.0 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1}	12/06/96
1997/1998	CIPC 16.6 mg kg^{-1}, CIPC 16.6 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1}; CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1}; CIPC 8.3 mg kg^{-1}plus 2,6-DIPN 16.6 mg kg^{-1} followed 70 DAFT[e] by 2,6-DIPN 16.6 mg kg^{-1}	11/11-12/97 & 12/02/97
1998/1999	CIPC 16.6 mg kg^{-1}; CIPC 16.6 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1}; CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 8.3 mg kg^{-1} followed 65 DAFT by 2,6-DIPN 8.3 mg kg^{-1}	11/09/98 & 1/13/99
1999/2000	CIPC 8.3 mg kg^{-1}; 2,6-DIPN 8.3 mg kg^{-1}; CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 8.3 mg kg^{-1}; CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 8.3 mg kg^{-1} followed 61 DAFT by 2,6-DIPN 8.3 mg kg^{-1}	12/13-14/99 & 2/14/00
2000/2001	CIPC 8.3 mg kg^{-1}; CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 4.14 mg kg^{-1}; CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 8.3 mg kg^{-1}; CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1}	11/08/00

[a]Amount applied based on mg a.i. kg^{-1} of tuber fresh weight.
[b]Dates treated are listed in month/day/year.
[c]Untreated control.
[d]Indicates a combination treatment.
[e]Days after first treatment.

trol, harvesting and storage conditions. Potatoes were loaded into storage bins on 1 and 2 November 1996, 1, 2, and 3 October 1997, 23 October 1998, 16 and 17 October 1999, and 9 October 2000. Except for the 1998/1999 storage season, in which bins were split between Ranger Russet and Snowden potatoes at 2,500 kg each, all other storage seasons with Russet Burbank tubers had between 4,000 and 4,500 kg of tubers per bin. The depth of the potato piles was approximately 1.4 m.

Storage Facility

The potato storage facility had four separate and independent rooms (bins), each with its own air-handling and refrigeration systems. Cooling coils (evaporators) were installed in the return air pathway. Auxiliary heat was provided by a 1000 W heating panel located in each fan room. The air temperature for each bin was set at its digital control panel. Humidification was supplied by water flow over evaporative pads in front of the fans. Air was circulated on a continuous basis throughout the storage season at 0.04 m^3 min^{-1}. A plenum distributed air beneath the potato pile through two 15.2-cm-diameter perforated PVC pipes 305 cm long. Perforations were 1.88 cm in diameter and were spaced every 20 cm in two rows along the pipe.

Bins were physically isolated from each other and each contained an injection port in the air plenum located in the access hallway behind the rooms. Treatment of potatoes in each bin was made using custom made small-scale thermal foggers.

At the completion of a storage season, bins were thoroughly cleaned of any potential residue. The sides, top, and floors were swept clean, and the outside doors were left open for a number of weeks to allow for air re-circulation and to minimize residues. Since complete 100% decontamination of the air circulation systems was not considered possible and since CIPC can move in air systems as small particles, it was deemed appropriate to assign bin spaces to the same treatment regime in repeat experiments when possible to limit possible contamination.

Application Apparatus and Chemicals

Aerosol fogging of sprout inhibitors was accomplished using a thermal fogger consisting of a hot plate for a heat source, a fog chamber and evaporation pan, a fan, an inlet and outlet with hoses for circulation of the inhibitor fog, an injection port, and a temperature probe. When the heat source attained a temperature of 500 C, the material was added to the chamber. Clear tubing was placed into the circulation hose for visual determination that all fog had left the fogger and entered the storage chamber. A window was inserted in the wall of the air plenum in one bin to facilitate viewing the movement of the fog into the distribution pipes.

Aceto Agricultural Chemicals Corp. (Lake Success, NY, USA) provided technical grade CIPC. Koch Chemical Company (Wichita, KS, USA) provided technical grade 2,6-DIPN. CIPC and 2,6-DIPN were applied as either solid or liquid formulations and were applied as described above. Liquid formulations were used in the 1996/1997, 1997/1998 and 1998/1999 storage seasons, and solid formulations were used in the 1999/2000 and 2000/2001 storage seasons.

Treatments, Application Conditions and Timing

Treatments, treatment dates, and cultivars treated for the five storage seasons are given in Table 1. Treatments were made after wound healing had occurred. Bin temperatures were initially set at 12.8 C and were gradually reduced to a range of 7.2 to 8.3 C. Research has shown that Russet Burbank potatoes store best at 7.2 C (Sparks 1965). The wound-healing time periods were 5 wk for the 1996/1997 storage season, 4 wk for 1997/1998, and 3 wk for the remaining storage seasons. The average relative humidity was ≥ 90%.

Sprout Measurements

Sprout measurements were made on a monthly basis. At the time of sampling, tubers were taken from each bin using pre-assigned sampling points. Sixty tubers were collected 30 cm below the surface of the pile. Three categories were used to assess the degree of sprouting based on sprout length. These categories were (1) no observable sprouts, (2) sprouts ≤ 3mm in length, and (3) sprouts > 3mm in length. The longest sprout was recorded for each collected potato. The combined averages of categories 1 and 2 are defined as Percentage Acceptable for Fresh Pack (% AFP).

Statistical Analysis

Sprout length data for each experimental year, by sampling date, were subjected to analysis of variance, (ARM 6.0, Gylling Data Management, Inc., Updated 1-06-2001). Treatment means were separated using Student-Newman-Keuls multiple means separation (P = 0.05).

RESULTS AND DISCUSSION

Two storage seasons, 1996/1997 and 1997/1998, involved testing CIPC at 16.6 mg kg^{-1} fw using the cultivar Russet Burbank (Table 2). In addition to the 16.6 mg kg^{-1} amount, CIPC was also tested at 11.0 mg kg^{-1} (in 1996/1997) and 8.3 mg kg^{-1} (in 1997/1998). Annual differences in treatments and sprouting of Russet Burbank precluded a comparison between years (Tables 2, 4). Lewis et al. (1997) noted a similar finding and attributed the year-to-year differences in sprouting characteristics to differences in growing degree-days, although it is also possible differences were due to uptake of CIPC. The general trend for the CIPC 16.6 mg kg^{-1} treatment was that it provided sprout control of 80% or better (as measured by %AFP) through April and part of May (Table 2). When 2,6-DIPN at 16.6 mg kg^{-1} was used with CIPC at 16.6 mg kg^{-1}, acceptable sprout suppression was maintained through June and part of July (Table 2). When the amount of CIPC used was reduced to either 11.0 or 8.3 mg kg^{-1} and used in conjunction with 2,6-DIPN at amounts of 16.6 mg kg^{-1} or multiples of that amount, the storage time with acceptable sprout suppression was maintained into June or July, depending upon the year (Table 2). The results of these two testing seasons using amounts of CIPC up to 16.6 mg kg^{-1}, showed that the addition of 2,6-DIPN extended sprout suppression, even at reduced rates of CIPC.

Snowden and Ranger Russet potatoes were evaluated using split bins in the 1998/1999 storage season (Table 3). For Snowden potatoes, the CIPC 16.6 mg kg^{-1} treatment provided sprout suppression at a minimum of 80% AFP or better (with the exception of April) up to May. The CIPC 16.6 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1} treatment provided ≥90% AFP into June. Except for the March reading, the double application treatment of 2,6-DIPN 8.3 mg kg^{-1} with CIPC 8.3 mg kg^{-1} resulted in sprout suppression of ≥85% into June. As was the case with Russet Burbank in the previous two seasons, results for the Snowden cultivar showed that the addition of 2,6-DIPN enhanced sprout suppression, even at reduced amounts of CIPC.

Ranger Russet tubers sprouted earlier then Snowden and statistically significant differences among treatments were not observed (Table 3). Although differences between treatments were not statistically different, the CIPC alone treatment dropped below 80% AFP in March, while CIPC 16.6 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1} remained acceptable into May

TABLE 2—*The effect of CIPC and 2,6-DIPN on sprout suppression for Russet Burbank potatoes in 1996/1997 and 1997/1998.*

Treatment[a]	Percentage Acceptable for Fresh Pack by Date (AFP %)					
	2/10/97	3/04/97	4/10/97	5/06/97	6/05/97	7/08/97
Untreated Control	71.7b[bc]	26.7b	0.0c	0.0c	0.0c	0.0d
CIPC 16.6 mg kg^{-1}	96.7a	86.7a	86.7b	81.7b	56.7b	53.3c
CIPC 16.6 mg kg^{-1} plus[d] 2,6-DIPN 16.6 mg kg^{-1}	95.0a	95.0a	98.3a	98.3a	90.0a	93.3a
CIPC 11.0 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1}	100a	93.3a	95.0a	95.0a	83.3a	80.0b
	2/11/98	3/10/98	4/17/98	5/18/98	6/25/98	7/13/98
CIPC 16.6 mg kg^{-1}	98.3a	95.0b	85.0b	90.0a	78.3b	76.7b
CIPC 16.6 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1}	100a	100a	100a	95.0a	95.0a	98.3a
CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1}	100a	100a	96.7a	95.0a	93.3a	88.3ab
CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1} followed 70 DAFT[e] by 2,6-DIPN 16.6 mg kg^{-1}	96.7a	100a	95.0a	91.7a	90.0a	73.3b

[a]Amount applied based on mg a.i. kg^{-1} fresh weight.
[b]Average of 60 potatoes.
[c]Means within month for the treatment year, followed by the same letter are not significantly different as derived from Student-Newman-Keuls multiple means separation (P = 0.05).
[d]Indicates a combination treatment
[e]Days after first treatment

(Table 3). A single application of CIPC at 8.3 mg kg^{-1} with 2,6-DIPN appeared as effective as the single CIPC 16.6 mg kg^{-1} treatment, suggesting that this cultivar would respond in a manner similar to both Russet Burbank and Snowden.

Reduced rates were tested in the last two storage seasons, 1999/2000 and 2000/2001 (Table 4). As with the first two testing seasons, differences between the 1999/2000 and 2000/2001 testing seasons were observed. For the 1999/2000 and 2000/2001 seasons, the reduced CIPC usage rate (8.3 mg kg^{-1}) resulted in sprout control of ≥85% AFP into March (2000) or April (2001) (Table 4). The 2,6-DIPN 8.3 mg kg^{-1} treatment with no CIPC lost sprout suppression in February/March. When CIPC and 2,6-DIPN were used together for the 1999/2000 season, the combined 2,6-DIPN treatment of 16.6 mg kg^{-1} maintained sprout control of 100% AFP for one additional month when compared to CIPC alone. A similar result was found in

TABLE 3—*The effect of CIPC and 2,6-DIPN on sprout suppression for Snowden and Ranger Russet potatoes in 1998/1999.*

	Percentage Acceptable for Fresh Pack by Date (AFP %)				
Treatment[a]	2/08/99	3/12/99	4/08/99	5/04/99	6/07/99
			Snowden		
CIPC 16.6 mg kg^{-1}	93.3a[bc]	88.3a	76.7b	83.3a	75.0b
CIPC 16.6 mg kg^{-1} plus[d] 2,6-DIPN 16.6 mg kg^{-1}	96.7a	90.0a	93.3a	98.3a	98.3a
CIPC 8,3 mg kg^{-1} plus2,6-DIPN 8.3 mg kg^{-1} followed 65 DAFT[e] by2,6-DIPN 8.3 mg kg^{-1}	96.7a	78.3a	85.0ab	86.7a	96.7a
			Ranger Russett		
CIPC 16.6 mg kg^{-1}	88.3a	73.3a	71.7a	75.0a	55.0a
CIPC 16.6 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1}	90.0a	88.3a	88.3a	80.0a	76.7a
CIPC 8,3 mg kg^{-1} plus2,6-DIPN 8.3 mg kg^{-1} followed 65 DAFT by 2,6-DIPN 8.3 mg kg^{-1}	86.7a	81.7a	76.7a	75.0a	76.7a

[a]Amount applied based on mg a.i. kg^{-1} of tuber fresh weight.
[b]Average of 60 potatoes.
[c]Means within months, followed by the same letter are not significantly different as derived from Student-Newman-Keuls multiple means separation (P = 0.05).
[d]Indicates a combination treatment
[e]Days after first treatment.

TABLE 4—*The effect of CIPC and 2,6-DIPN on sprout suppression for Russet Burbank potatoes in 1999/2000 and 2000/2001.*

	Percentage Acceptable for Fresh Pack by Date (AFP %)			
Treatment[a]	2/14/00	3/13/00	4/13/00	5/10/00
CIPC 8.3 mg kg^{-1}	100a[bc]	100a	26.7c	5.0b
2,6-DIPN 8.3 mg kg^{-1}	91.7a	75.0b	20.0c	3.3b
CIPC 8.3 mg kg^{-1} plus[d] 2,6-DIPN 8.3 mg kg^{-1}	98.3a	98.3a	61.7b	55.0a
CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 8.3 mg kg^{-1} followed 61 DAFT[e] by 2,6-DIPN 8.3 mg kg^{-1}	100a	100a	100a	60.0a
	2/02/01	3/02/01	4/02/01	5/02/01
CIPC 8.3 mg kg^{-1}	96.7a	95.0ab	86.7a	46.7b
CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 4.15 mg kg^{-1}	100a	91.7b	91.7a	76.7a
CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 8.3 mg kg^{-1}	98.3a	100a	93.3a	76.7a
CIPC 8.3 mg kg^{-1} plus 2,6-DIPN 16.6 mg kg^{-1}	100a	100a	88.3a	80.0a

[a] Amount applied based on mg a.i. kg^{-1} of tuber fresh weight.
[b] Average of 60 potatoes.
[c] Means within month for the treatment year, followed by the same letter are not significantly different as derived from Student-Newman-Keuls multiple means separation (p=0.05).
[d] Indicates a combination treatment
[e] Days after first treatment

the 2000/2001 season when all combined 2,6-DIPN plus CIPC treatments provided significantly better sprout suppression into May when compared to CIPC used alone (Table 4).

A general conclusion that can be drawn from this five-year storage season study is that either a single or dual application of 2,6-DIPN when used with CIPC can effectively suppress potato sprouting for a longer period of time than that for CIPC used alone. When the standard amount of CIPC at 16.6 mg kg^{-1} was reduced by one half to 8.3 mg kg^{-1}, as was the case with the last two testing seasons, then the amount of 2,6-DIPN needed for improved sprout suppression in 1999/2000 was double (16.6 mg kg^{-1}), demonstrating that at reduced amounts of CIPC, the effective ratio between 2,6-DIPN and CIPC could be greater than 1:1. However, when the level of CIPC used was at 16.6 mg kg^{-1}, as was the case with the first two years, the amount of 2,6-DIPN needed to extend sprout suppression was equal to that amount of CIPC used, which was at 16.6 mg kg^{-1} for each chemical, or an effective ratio of 1:1. When compared to previously published work, the sprout suppression effect of using the two chemicals together was equal to or better than that reported for multiple applications of DMN (Beveridge et al. 1981b), or for multiple applications of high use amounts of DMN or DIPN (Lewis et al, 1997). When 2,6-DIPN was used alone at the amount tested, it did not provide sufficient sprout control beyond February. Previous work (Lewis et al. 1997) suggested that higher amounts of 2,6-DIPN would be needed for sprout suppression if the chemical was used by itself. In summary, when 2,6-DIPN is used with CIPC in amounts from 8.3 to 16.6 mg kg^{-1}, there is generally an enhancement of potato sprout suppression and the potential to reduce the use of CIPC by as much as 50%.

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