MS Thesis: Mst. Shumana Akter

DE SI GN AN D DE VE L OP M E NT OF AL OW-C OST SOL AR P OWE RE D ST ORAGE SY ST E M T O E XT E ND T HE SHE L F L I FE OF L I T CHI (Litc hi c hi ne ns is) F RU I T S AT HE SI S BY M ST. SHUM AN AAKT E R St ude nt N o: 1707105 Se s s ion: 2022-2023 T he s is Se me s te r : Ja nuar y-J une/20 24 M AST E R OF SCI E NC E IN FAR M P OWE RAN DM AC HI NE RY DEPA RTM ENT OFAGRI CULTURA LAND I NDUSTRIA L ENGINE ERING HAJEE M OH AM M AD DANES H S CIENCEAND TECHNOLOG Y UNIVE RSIT Y, DINAJPU R-5200, B ANGLADES H JUNE-2024

DE SI GN AN D DE VE L OP M E NT OF AL OW-C OST SOL AR P OWE RE D ST ORAGE SY ST E M T O E XT E ND T HE SHE L F L I FE OF L I T CHI (Litc hi c hi ne ns is) F RU I T S AT HE SI S BY M ST. SHUM AN AAKT E R St ude nt N o: 1707105 Se s s ion: 2022-2023 T he s is Se me s te r : Ja nuar y-J une/20 24 S u b mit t ed t o th e Dep art men t ofAgricu lt u ra l an d In d u st rial En gi n eerin g Haj ee M oh ammad Danesh S cience an d Tech n ology Uni versit y, Din aj p u r in p art ial fu lfi llmen t of t h e req u i re men t fo r t h e d egree of M AST E R OF SCI E NC E IN FAR M P OWE RAN DM AC HI NE RY DEPA RTM ENT OFAGRI CULTURA LAND I NDUSTRIA L ENGINE ERING HAJEE M OH AM M AD DANES H S CIENCEAND TECHNOLOG Y UNIVE RSIT Y, DINAJPU R-5200, B ANGLADES H JUNE-2024

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Dedi cate d To M y Bel ove d Pa re nt s

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ii AB ST RACT P o st-har vest lo sse s o f lit c hi in Ba ng lade s h ar e sig nific a nt ly hig h, pr imar ily due to impr o per ha nd ling, t r anspo rt at io n, a nd st o r age co nd it io ns. T his r e sear c h a ims t o addr ess t hese issue s b y des ig ning a nd co nst r uct ing a lo w-co st so lar-po wer ed sto r age st r uct ur e spec ific a lly fo r t he sho r t-t er m st o r age o f lit c hi fr u it s. T he st ud y a lso a sse sse s t he e ff ic ie nc y o f t his s mar t sto r age st r uct ur e in r educ ing po st-har vest lo sse s and ma in t aining t he qualit y o f lit c hi fr u it s. A so lar-po wer ed evapo r at ive co o ling st or age syst e m was deve lo ped to pro lo ng t he she lf li fe o f lit c h i fr u it s. T he s yst e m co mpr is es t hr ee ma in co mpo nent s: a sto r age unit , a coo ling mec ha nis m, and a co nt ro ller unit . T he co o ling s yst e m use s a coo ling pad, fa n, pu mp, and wat er t ank to ma int a in r educed t e mper at ur e and hu mid it y le ve ls, while so lar pane ls supp ly po wer. A micr o co ntro ller equ ipped w it h t e mper at ur e, humid it y, et hyle ne, a nd car bo n d io xide se nso r s mo nit o r s sto r age co nd it io ns. T he s yst e m's p er fo r ma nce was e va luat ed aga inst t r adit io na l sto r age met ho ds, inc lud ing o pen ba mbo o and p la s t ic ba sket s, r efr iger at io n in po ly bag s, and t he deve lo ped st o r age unit , us ing 50 lit c hi s a mp le s fo r each met ho d. T he so lar-po wer ed sto r age s yst e m ma int a ined a st able int er na l te mpe r at ur e o f 27. 42°C and r elat ive hu mid it y o f 64. 81% , co mpar ed to ambie nt co nd it io ns o f 31. 43°C a nd 75. 13% hu mid it y. T he po st har ve st qua lit y par a met er s o f lit c his st o r ed in t he de ve lo ped s yst e m s ho wed a phys io lo g ica l we ig ht lo s s ( P LW) o f 19% , fir mne ss betwee n 10 N and 15 N, and tot al so lu ble so lids ( T S S ) o f 17%. T he hig he st weig ht lo ss ( 28. 37%) o ccur r ed in ba mbo o basket s, while t he hig hest fir mnes s ( 16. 03 N) and T S S ( 17. 95%) wer e r ecor ded in p la st ic basket s and r e fr ig er ato r s, r espect ive ly. T he e vapo r at ive va lue o f 27. 39) . T he s yst e m de mo nst r at ed a bene f it-co st r at io o f 1. 25, hig hlig ht ing it s eco no mic fea s ib ilit y fo r s ma ll-sca le far mer s. T his st udy co nc lude s t hat t he so lar-po wer ed evapo r at ive co o ling st o r age s yst e m is a sust a ina ble , lo w-co st so lut io n fo r r educ ing lit c hi po st-har vest lo sses, enha nc ing mar ket abilit y, a nd impr o ving pr o fit abil it y. Fut ur e r esear ch sho u ld fo cus o n sca ling t he des ig n fo r larger app licat io ns a nd int egr at ing adva nced pr eser vat io n t echnique s to fur t her ext end t he she lf li fe o f lit c hi and o t her per is ha ble fr u it s.

iii AB B RE VIAT ION C WN Chit o sa n Wat er Nan co mpo s it e T S S Tot al S o lu ble S o lid s PH P ot ent ia l o f H ydr o gen I DE I nt egr at ed Deve lo p me nt E nvir o nme nt CO2 Car bo n D io xide C2H4 Et hyle ne

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1 CHAP T E R-I I NT RODU CT I ON 1.0 B ackg rou n d Lit c hi (L it chi chinensis) is a seaso na l fr u it t hat is w ide ly cu lt ivat ed in t ro pica l a nd su bt r o pica l r eg io ns ar o und t he wor ld. This fr u it tr ee, whic h t hr ives in spec if ic c limat ic co nd it io ns, is t her e fo r e cult ivat ed in a lim it ed nu mber o f co unt r ies ( S ing h et al. , 2023). L it chi is r e no wned fo r it s hig h nut r ie nt va lue, att r act ive co lo r , and de lic io us t ast e. T he fr u it ha s a n o blo ng s hap e, br ig ht r ed sk in, and sweet , ju ic y pu lp. L it c hi is a n e xce lle nt so ur ceo f e sse nt ia l nut r ie nt s, inc lud ing vit a mins, miner a ls, a nd bio act ive co mpo und s suc h as phe no lic s and fla vo no id s, whic h po ssess nat ur a l ant io xida nt pro pert ies ( Chad ha, 2001; Lu ximo n-Ra mma et al. , 2003) . The se bio act ive co mpo ne nt s he lp to r educe sca ve ng ing r eact ive o xyge n spec ie s a nd cho le st er o l le ve ls, t her e by lo wer ing t he r isk o f d is ease s suc h as car d io va scu lar d ise ase, s ma llpo x, and d yspep s ia ( Gao et al. , 2017; Morto n et a l. , 2000; S u et al. , 2016). Wa ll ( 2006) suggest s t hat co nsu ming 14-17 lit c his da ily ca n fu lf il l an adu lt 's da il y r equ ir e me nt o f vit a min C. 1. 1 Lit ch i Prod u ct ion Lit c his o r ig ina ll y ca me fr o m so ut her n China a nd wer e int ro duced to t he I nd ia n su bco nt ine nt by M ya nmar, Taiw a n, T ha ila nd, I ndo nes ia, Viet na m, I nd ia, P ak ist an, a nd Ba ng lade s h ar o und t he end o f t he 17t h cent ur y. To day, China a nd I ndia r e ma in a mo ng t he to p r egio ns for lit ch i cu lt ivat io n. L it c hi is be lie ved t o have bee n br o ught to Bang lade s h fr o m M ya nmar ( Be la l, 2023) . While lit c hi gr o ws t hr o ugho ut Bang lade s h, t he pr imar y cu lt ivat io n ar eas inc lude t he d ist r ict s o f D ina jpur, Ra js ha hi, Ra ngpur, Khu lna, Dhaka, Kus ht ia, S ylhet , and Chit t ago ng. Acco r d ing t o dat a fr o m t he Ba ng lade s h Bur eau o f S t at ist ic s ( 2022) , lit c hi pr o duct io n in Ba ng lades h has s ho wn s ig nif ica nt gro wt h o ver the past s ix year s. I n t he 2017-2018 fisc a l year, t he pro duct io n was 40, 886 met r ic to ns. Over t he follo w ing t wo year s, pro duct io n incr ea sed to 92, 958. 42 met r ic to ns. T his dat a hig hlig ht s t he incr ea s ing impo rt ance o f lit c h i cu lt ivat io n in Ba ng lade s h, as illust r at ed in F igur e 1. 1.

2 Figu re 1. 1: Annu a l lit c hi P r o duct io n in Ba ng lade s h ( 2017-2018to 2021-2022) ( So ur ce: Bang lad es h Bur eau o f S t at ist ics, 2022) D ina jpur, lo cat ed in t he no rt her n par t o f Ba ng lad es h, co ver s an ar ea o f 3, 437. 98 km². T his r eg io n is a s ig nif ic a nt pro ducer o f lit c hi due to it s fa vo r able geo gr aphic a l lo cat io n, so il co nd it io ns, a nd r a infa ll pat t er ns. T he d ist r ict has a n a ver age e le vat io n o f 37 met er s a bo ve se a le ve l, whic h fur t her suppo rt s lit c hi cu lt ivat io n. Dat a ind ic at es t hat lit c hi pr o duct io n in D ina jpur ha s gr adually incr ea sed o ver t he ye ar s. I n t he 2017-2018 fisca l year, t he pro duct io n was 3, 097 met r ic to ns. Over t he next five year s, t his f igur e co nt inued to r is e, demo nst r at ing t he gr o wing impo r t ance o f lit c hi cu lt ivat io n in t he r eg io n. T his t r end is illust r at ed in ( F igur e 1. 2)

3 Figu re 1. 2: Annua l lit c hi P r o duct io n in D ina jpur ( 2017-2018to 2021-2022) ( So ur ce: Bang lad es h Bur eau o f S t at ist ics, 2022) 1. 2 Post-h arvest Losse s of Lit ch i I n Ba ng lades h, po st-har ve st lo sse s o f lit c his ar e est imat ed to be bet ween 25-30% (T BS , 2023) . T hese lo sses can o ccur due to var io us fact or s, inc lud ing impr o per hand ling, t r anspo rt at io n, sto r age, and envir o nme nt a l co nd it io ns. P o st-har vest lo sses o ft en st e m fr o m phys ica l da mage dur ing har vest ing, inad equat e packag ing t hat lead s to br u is ing a nd deca y, t emper at ure fluct uat io ns t hat affect she lf li fe, and pest infe st at io ns. Mec ha nica l in jur ies pr imar il y ha ppen dur ing har ve st ing a nd t r anspo rt at io n, pr o cesses t hat have no t been adequat e ly o pt imiz ed. Lit chi fr u it s, w it h t he ir t hin per icar p, de licat e fle s h, and hig h-wat er co nt ent , ar e pro ne to cell r upt ur e, disr upt io n, and separ at io n due to co llis io n a nd pr essur e ( Che n et al. , 2013). Mec ha nica l in jur y cr eat es pat hwa ys fo r pat ho genic bact er ia t o ent er, acceler at ing fr u it deca y. S ever e ly deca ye d lit c hi fr u it s lo se t he ir co mmer c ia l va lue a nd mu st be d iscar ded t o pr event t he spr ead o f bact er ia to ot her lit c his. T he imp act o f mec ha nica l in jur y o n t he lit c hi per icar p ha s bee n ext e ns ive ly st udied ( Che n et al. , 2013; 2013b) . Apar t fr o m mec ha nica l d a mage, lit c hi fr u it decays ver y qu ick ly a ft er be ing har vest ed ( Dhar ini et al. , 2008). Desp it e adva nce me nt s in pr eser vat io n t echno lo g ie s t hat can par t ia ll y s lo w t he r at e o f deca y ( Kha n et a l. , 2012) t he r apid det er io r at io n o f lit c hi fr u it aft er har vest co nt inues t o be a ma jo r cha lle ng er.

4 I mpr o ved liv ing st and ar ds ha ve incr eas ed de ma nd fo r fr es h fo o d w it h e xt ended st o r aget imes. Co ld sto r age he lp s e xt end t he s he lf life o f lit c hi fr u it , r esu lt ing in le ss no t ice a ble c ha nge s in it s appear a nc e, part icu lar ly dur ing t he ear ly st ages ( S a i Xau et al. , 2020) . Amo ng t he d iffer e nt pr e-coo ling t echnique s, evapo r at ive co o ling st and s o ut as a st r aig ht fo r war d, eas y-to-use, and co st-effe ct ive met ho d. T his t echnique is a ffo r dable a nd can be eas il y imp le me nt ed by far mer s o n t he ir o wn fa r ms. T he aim o f t his st ud y was to eva luat e t he effect ive ne ss o f evapo r at ive co o ling in r educ ing per icar p br o wning and pr eser ving t he po st har ve st qualit y of lit c hi fr u it s dur ing st o r age ( Shilpa et al. , 2021). A so lar po wer sto r age syst e m is a set up t hat stor es t he sur plu s energ y ge ner at ed by so lar pane ls fo r lat er use. T hese s yst e ms ar e cr uc ia l fo r mak ing so lar energ y a va ila ble w he n t he sun is no t shining su c h as dur ing t he nig ht o r clo udy d a ys. S o lar o r photo vo lt a ic ( P V) ce lls ge ner at e e lect r ic it y by d ir ect ly co nver t ing su nlig ht . T he y ca n har nes s bo t h dir ect and scatt er ed so lar r adiat io n t o pro duce elect r ic a l e nerg y ( Ko ber le et al. , 2015) . T he pr o cess o f co nver t ing so lar e nerg y int o e lect r ic it y t hr o ugh pho to vo lt a ic ( P V) ce lls o per at e wit h e ff ic ie nc y r at ing s t hat r ange fr o m 7% to 40% depend ing large ly o n t he se mico nduct or mat er ia l u sed in t he ce ll co nst r uct io n ( Makk i et a l. , 2015). Whe n su nlig ht st r ike s t he ce ll, t he energ y cau ses e lect r o ns to be fr eed fr o m t he ir ato ms, ena bling t he m t o f lo w t hro ugh t he mat er ia l. T his gener at e dir ec t cur r ent ( DC) elect r ic it y w hic h is t hen co nver t ed int o alt er nat ing cur r ent ( AC) e lectr ic it y by a po wer inver t er, t he fr o m t yp ica ll y used fo r supplying po wer to supp ly line (P ic iu et al. , 2014) Cur r ent ly, t wo co nve nt io na l met ho ds ar e used fo r lit c hi qua lit y det ect io n: t he se nso r y det ect io n met ho d ( Alves et a l. , 2011) and t he phys ico c he mica l det ect io n met ho d ( Huang et a l. , 2016) . T he senso r y det ect io n met ho d r elie s o n hu ma n se ns es t o eva lu at e qualit ie s lik e per icar p co lo r, fla vo r, and fr agr a nce. I n co nt r ast, t he phys ico c he mica l det ect io n met ho d mea sur es t he tot al so lu ble so lid co nt ent , t it r at able ac id it y, a nd we ig ht t hr o ugh che mica l ana lys is o r phys ica l measur e me nt s. While t he se nso r y det ect io n met ho d pro vides d ir ect eva luat io ns by hu ma ns, it is time-co nsu ming, la bo r-int ens ive, and pr o ne t o hu ma n er r o r. T he phys ico c he mica l det ect io n met ho d, t ho ugh o bject ive a nd pr ec is e, is de st r uct ive, co mp le x, a nd t ime-co nsu ming. As a r esu lt , t hese t r adit io na l met ho ds ar e inadequ at e fo r t he e vo lving lit c h i indust ry.

5 Desp it e adva nces in mac hine vis io n ( X io ng et al. , 2011) and spect r um t echno lo g ies ( X io ng et a l. , 2018) t hat enable qu ick a nd int e llige nt det ect io n o f var io us agr icu lt ur a l pr o duct s, t he y ar e ine ffe ct ive in det ect ing t he qua lit y o f st or ed lit c hi due toover lapp ing fr u it dur ing st o r age. I ndeed, t he per icar p ( o ut er la yer ) o f lit c hi fr u it is e xcept io na ll y de licat e and hig hly per is ha ble. I t s she lf li fe under a mbie nt co nd it io ns t yp ica ll y la st s no mo r e t han 24 to 72 ho ur s, po sing a cha lle ng e fo r sto r age and t r anspo rt at io n. T his necess it at es t he use o f r ap id coo ling a nd spec ia lized st o r age met ho ds to ma int a in it s qua lit y and e xt end it s s he lf life ( Ku mar, 2000) . L it c hi fr u it canno t be kept fo r mo r e t han a few da ys at roo m t emper at ur e aft er har ve st . One t r adit io na l t ec hniqu e fo r sho r t-t er m st o r age is t o p lace t he m in per fo r at ed pla st ic bags o r co nt ainer s a nd st or e t he m in a co o l, dr y p la ce suc h as a r e fr iger at o r. T his he lps ma int a in t he ir fr e s hne ss a nd pr o lo ng t he ir s he lf li fe fo r a few da ys. Add it io na ll y, wr app ing ind iv idua l lit c his in p aper can he lp pr eve nt br u is ing and spo ilage. S ho rt-t er m sto r age o f lit c hi is cr uc ia l fo r ma int a in ing it s fr es hne ss, fla vo r, and nutr it io na l va lue. P ro per sho rt-t er m sto r age he lp s pr eser ve fr e shnes s, r et ain fla vo r and t ext ur e, min im ize po st-har vest lo sses, ma int a in nut r it io na l va lue, and ext end mar ket ava ila bil it y. 1. 3 Research Ob j ect ives: To desig n a nd co nst r uct a lo w-co st so lar-po wer ed sto r age str uct ur e spec ific a lly fo r sho r t-t er m st or age o f lit chi fr u it s, fo cus ing o n enha nc ing t he ir po st-har ve st she lf lif e and ma int a ining t he ir qua lit y. To assess t he e ffic ie nc y o f t he s mar t stor age str uct ur e in r educ ing po st-har vest lo sses o f lit c hi fr u it s acr o ss var io us st or age dur at io ns.

6 C hap te r-II RE VI E W OF L I TE RAT UR E Kaur et al. ( 2013) invest igat ed t he effect s o f a mbient t emp er at ur e and co ld st o r age co nd it io ns o n t he s ize, we ig ht , and vo lu me o f lit c hi fr u it s using e ig ht dif fer e nt tr eat me nt s. T he t r eat me nt s inc luded C hit o san ( 1% ) , Asco r bic Ac id ( 5% and 10% ), C it r ic Ac id ( 10% and 15% ) , and Oxa lic Ac id ( 5% and 10% ) . T he st udy e va luat ed c ha nges in fr u it s ize, we ig ht , vo lu me, and c he mica l pr o pert ies o n t he 1st , 3r d, 5th, and 7t h da ys at roo m t e mper at ur e. Aft er se ve n da ys, u nt r eat ed fr u it s spo iled, w hile t he 1 % chit o san t r eatme nt was mo st effect ive in s lo w ing t he decr eas e in fr u it s ize, we ig ht , and vo lu me. Add it io na ll y, fr u it s t r eat ed wit h 5% o xa lic ac id had t he hig he st tot al so lu ble so lid s ( T SS ) , and t ho se tr eat ed wit h 10% o xa lic ac id had t he hig hest tot al sugar co nt ent . T hese find ing s suggest t hat 1% chit o san t r eat me nt co uld be a via ble met ho dto ext endt he s he lf life o f lit c hi fr u it s. Ku mar et al. ( 2017) fo cused o n t he issue s r e lat e d to t he dr ynes s a nd cr ack ing o f t he o ut er la yer o f lit c hi fr u it s due t o poor po st-har ve st ha nd ling pr act ices. Cr ack ing, w hic h ca n o ccur be fo r e and dur ing fr u it gro wt h, allo w s har mfu l micr o o r ganis ms t o ent er t he fr u it dur ing sto r age and t r anspo rt at io n, espec ia ll y at lo w t emper at ur es. T he y hig hlig ht ed t hat t he dr ying and br o wning o f t he o ut er skin af fect bo t h t he appear anc e a nd t ast e o f t he fr u it . T o mit ig at e t hese issu es, t he y suggest ed t he use o f su lfur d io xide ( S O2) dur ing st or age and t r anspo rt at io n to ma int a in fr u it qua lit y a nd pr eve nt br o wning. Res hi et a l. ( 2013) exa mined t he impact o f differ e nt po st-har ve st tr eat me nt s o n t he qualit y o f lit c hi fr u it s, fo cus ing o n wat er lo ss, br o wning, and t he ro le o f ca lc iu m in fr u it ag ing. Sto r age exper ime nt s at ( 32 ± 3) °C o ver t en da ys r eve a led a st eady dec line in we ig ht lo ss, ac id it y, and asco r bic ac id, w it h an init ia l incr ease fo llo we d by a decr ease in tot al so lu ble so lids. S pec if ica ll y, we ig ht lo ss decr eased fr o m 1. 33% to 5. 08%, ac id it y fr o m 0. 41% to 0. 22% , and asco r bic ac id fr o m 42. 64 to 25. 71 mg/100 mL over t en da ys. Tot al so lu ble so lid s init ia ll y incr ea sed fr o m 20. 17 Br ix to 26. 64 Br ix ( up to six da ys) be fo r e decr eas ing t o 17. 06 Br ix ( up to t en da ys) . T he st udy a lso fo und t hat calc iu m t r eat me nt s he lped t o pro lo ng s he lf life by pr eser ving fr u it fir mnes s a nd r educ ing r esp ir at io n r at e, t is sue br eakdo wn, and dis eas e o ccur r ence, while su lfur tr eat me nt s he lped ma int a in o ver a ll fr u it qua lit y. S har min et al. ( 2020) inve st ig at ed t he she lf li fe and qua lit y o f lit c hi fr u it s us ing var io us t r eat me nt s, inc lud ing ca lc iu m c hlo r ide, o xa lic a c id ( 2 mM) + ba vist in ( 0. 05% ) + ice, ice

7 t r eat me nt a lo ne, ice + o xa lic ac id ( 2 mM) , c lea n wat er wash, a nd a co nt ro l gr o up ( no t r eat me nt ) . Tr eat ed lit c hi fr u it s s ho wed s ig nif icant impr o ve me nt s in de la ying spo ilage, ext end ing s he lf li fe, ma int a in ing fir mne ss, r educ ing per icar p br o wning, a nd pr eser ving T S S , t it r at able ac id it y, vit a min E co nt ent, and pit qua lit y co mp ar ed to t he co ntro l gr o up. Not ably, t he co mbinat io n o f o xa lic ac id ( 2 mM) + ba vist in ( 0. 05%) tr eat me nt , alo ng w it h lo w-dens it y po lyet hyle ne ( LDPE ) packag ing at ambie nt t empe r at ur e, exhibit ed t he lo west r at e o f we ig ht lo s s a nd d isea se inc ide nc e. T hese c he mic a l t r eatme nt s e ffect ive ly e xt ended t he s he lf li fe o f lit c hi fr u it s while ma int a in ing t he ir nut r it io na l qua lit y. Ma hmo o d et al. ( 2017) invest igat ed t he e ffect s o f d iffer e nt sto r age cond it io ns o n lit c hie fr u it s. Fr u it s st or ed in o pen co nd it io ns r ap id ly lo st weight and be ca me unmar ket able w it hin t hr e e da ys due t o per icar p br o wning. I n co nt r ast , t ho se st or ed in po lyet hyle ne bags e xper ie nc ed r educed we ig ht lo ss and r et ained t he ir per ic ar p co lo r bett er. Ho wever, deca y s ympt o ms appear ed in fr u it s st or ed at ambie nt t emper at ur es, r egar d les s o f be ing in po lyet hyle ne bags o r ba mbo o ba sket s lined w it h lit c hi lea ves. No deca y s ympt o ms wer e o bser ved in fr u it s st o r ed at 5°C, hig hlig ht ing t he impo rt ance o f lo w-t emper at ur e stor age. Ku mar et al. ( 2020) exp lo r ed t he use o f a Chit o san: P ullu la n ble nd a nt imicr o bia l ed ib le co at ing to impr o ve t he stor age life and qua lity o f lit c hi fr u it s. T his co at ing r egu lat ed tot al so lu ble so lids ( T S S ) and tot al ac id it y ( TA) , decr eased pH, pheno lic co nt ent , fla vo no id co nt ent , and ant io xida nt act ivit y, t hus ext end ing t he she lf life o f t he fr u it s. T he applicat io n o f t his ed ib le co at ing sho wed pot ent ia l co mmer c ia l app licat io ns fo r t he pr imar y a nd min ima l pr o cess ing o f fr u it s a nd veg et ables, ma int a in ing t he ir qua lit y dur ing st o r age. Kau s hik et al. ( 2014) st udied t he impact o f hig h-p r essur e pr o cess ing o n t he 'Bo mba i' var iet y o f lit c hi fr u it s dur ing r e fr ig er at ed sto r age. T his me t ho d incr ea sed co lo r differ e nce a nd so lu ble so lid s, decr eased pH, r educed micr o bia l co unt s, and ext e nded t he she lf li fe up to 32 days, co mpar ed t o 12 days fo r unt r eat ed fr u it s st or ed at 5°C. T his sugge st s t hat hig h-pr essur e pr o cess ing ca n e ffect ive ly pr o lo ng t he s he lf life o f lit c hi fr u it s. Deng et a l. ( 2018) eva lu at ed cha nge s in p he no lic pr o file s a nd a nt io xida nt act ivit y o f lit c hi per icar p dur ing st o r age at 4°C fo r seve n da ys and at roo m t emper at ur e fo r 72 ho ur s. T he resu lt s ind icat ed t hat stor age at 4°C pr eser ved mo r e phe no lic s and r et ained hig her ant io xida nt act ivit y co mpar ed to roo m t emper at ur e stor age, mak ing it a mo r e e ffect ive met ho d fo r ma int a in ing lit c hi per ic ar p qua lit y.

8 Devi ( 2018) fo und t hat a t r eat me nt invo lving a 10-minut e dip in HNO3 ( 1. 5% ) fo llo wed by a 15-minut e d ip in Ca C l2 ( 2% ) r esu lt ed in t he hig hes t senso r y sco r es and succe ss fu ll y incr ease d t he she lf li fe o f lit c hi fr u it s. T his t r eat me nt was effe ct ive in pr eser ving t he senso r y qua lit ie s and e xt end ing the fr u it 's s he lf life. T a lukder et al. ( 2020) co mpar ed t r eat ed and untr eat ed lit c hi fr u it s a nd fo und t hat stor ing lit c hie in 75 µ m po lypr o p yle ne bag s at 4°C pr ovided t he be st stor age per fo r ma nce. Fr u it s sto r ed under t hese co nd it io ns had t he lo nge st she lf life ( 23. 67 da ys) , s ig nif ic a nt ly o ut per fo r ming unt r eat ed fr u it s, whic h last ed o nly thr ee da ys. T his st ud y co nc lud ed t hat using 75 µ m po lypr o p yle ne bag s at lo w t emper at ur es is t he best appro ach fo r ext end ing lit c hi s he l f life w it ho ut co mpr o mis ing fr u it qua lit y. Mpha hle le et a l. ( 2020) disco ver ed t hat lit c hi fr u it s co uld be e ffect ive ly ma int a ined fo r up to nine da ys w it ho ut decay in no n-per fo r at ed and 1. 1 mm p er fo r at ed cla ms he ll t r a ys. T he st ud y invo lved st o r ing Maur it iu s lit c hi fr u it s in c la ms he ll t r ays w it h var io us per fo r at io n s ize s at 1°C fo r 15 da ys, fo llo wed by t wo days at 12°C fo r she lf st ud y. T his st or age met ho d pro ved e ffect ive in pr eser ving fr u it qua lit y. S he n et a l. ( 2024) r eport ed t hat applying a lg inat e o ligo sacc har ides to lit c hi fr u it s r esu lt ed in impr o ved co lo r r et ent io n, r educed wat er lo ss, ma int a ined har d nes s, and lo w er r at es o f mo ld in fect io n co mpar ed t o unt r eat ed fr u it s. T his t r eat ment sho ws pr o mise fo r enha nc ing t he po st-har vest qua lit y o f lit c hi fr u it s. Ku mar et a l. ( 2024) fo und t hat a co mbinat io n o f met hio nine ( 0. 1%) , cyst e ine ( 0. 1%) , E DTA ( 0. 1% ), o xa lo acet ic ac id ( 1% ), asco r bic ac id ( 1% ) , cit r ic ac id ( 1% ), and pot ass iu m met abis u lf ide ( 0. 5% ) effec t ive ly r educed we ig ht lo ss and pr eser ved se nso r y att r ibut es in lit c hie fr u it s. T his co mbinat io n o f t r eat me nt s o ffer s a co mpr e he ns ive appr o ach to ma int a in ing fr u it qua lit y dur ing st or age. Ja ved et a l. ( 2023) demo nst r at ed t hat lit chi fr u it s t reat ed wit h VT S B exhib it ed lo wer le ve ls o f br o wning degr ee ( BD) , br o wning inde x ( BI ) , we ig ht lo ss, so lu ble qu ino ne ( S Q) , r elat ive e lect r o lyt e leakage ( RE L) , a nd ma lo nd ia ld e hyde ( MD A) co mpar ed t o untr eat ed co nt ro l fr u it s. T hese f ind ings sugge st t hat VT S B tr eat me nt can s ig nif ica nt ly e nha nce t he po st-har vest qua lit y o f lit c hi fr u it s. Kha na l et a l. ( 2023) inve st igat ed t he e ffe ct s o f d iffer e nt co ncent r at io ns o f pot ass iu m met abisu lf it e and B a vist in o n lit c hi fr u it s st o r ed at ambie nt co nd it io ns. T he y fo u nd t hat spec ific co nce nt r at io ns r esu lt ed in min ima l deca y lo ss, lo west phys io lo g ica l we ig ht lo ss ( P LW) , hig he st tot al so lu ble so lids ( T S S ), and ma ximu m a sco r bic ac id le ve ls, ind icat ing t hese t r eat me nt s' e ffect ive ne ss in ma int a in ing lit c hi qua lit y dur ing st o r age.

9 Ha yat et al. ( 2024) st udied t he effect s o f differ e nt ac id t r eat me nt s o n lit c hi fr u it s. T he y fo und t hat a t r eat me nt wit h 1. 5% nit r ic ac id, 3% o xa lic acid, and 3% asco r bic ac id, fo llo wed b y sto r age at 4±1°C fo r 12 days, s ig nif ica nt ly r educed per icar p br o wning a nd incr ea sed ant io xida nt act ivit y. T his t r eat me nt also enha nced cat ala se and super o xide d is mut ase act ivit ies, ind icat ing impr o ved pr eser vat io n o f fr u it qua lit y. Fa ng et a l. ( 2024) exa mined t he e ffect s o f t r eat ing lit c hi fr u it s w it h WS P. T he t r eat me nt r esu lt ed in hig her L va lue, incr eased tot al a nt ho c ya nin co nt ent , gr eat er per ic ar p wat er co nt ent, and a t hicker per icar p. It effect ive ly suppr essed e lect r o lyt e leakage a nd ma int a ined hig her asco r bic ac id co nt ent in t he ar il. Add it io na lly, WS P t r eat me nt r educed t he act ivit y and e xpr ess io n o f br o wning-r e lat ed genes, suggest ing it as an effect ive met ho d to dela y p er icar p br o wning and ma int a in lit c hi fr u it qua lit y. Kap ila n et a l. ( 2023) pro vided a co mpr e he ns iv e r eview o f e vapo r at ive co o ling s yst e ms, exa min ing t he ir des ig n, o per at io n, and app lic at io n. T he y hig hlig ht ed t he sig nif ica nce o f evapo r at ive co o ling in pr eser ving per is ha ble pr o duct s, inc lud ing fr u it s like lit c hi ( F igur e 2. 1) Figu re 2. 1: I mpo rt ant var ia bles a ffe ct ing E CS per fo r ma nce (Ad apt ed fr o m Kap li la n, 2023). S hilpa et al. ( 2021) invest igat ed t he effect s o f evapo r at ive co o ling ( E C) o n lit c hi fr u it s. S tor ing lit c hi fr u it s in co r r ugat ed fiber bo ar d bo xes at 2-3°C a nd 90-95% hu mid it y, a lo ng w it h a 6-ho ur E C t r eat me nt , sig nific a nt ly r educed weig ht lo ss and ma int a ined hig her le ve ls o f

10 f ir mne ss, tot al so lu ble so lids ( T S S ) , acid it y, a nt ho c ya nins, a nd t ot al p he no ls o ver a fo ur-week per io d. E C expo sur e effect ive ly min im ized fr u it br o wning fo r up to 14 da ys a nd decr ease d enz yme act ivit ies ( P P O and P OD) , ext end ing t he stor age life o f lit c hi fr u it s co mpar ed to unt r eat edo nes. Huang et a l. ( 2023) deve lo ped a nd t est ed a ne w spr a y hydr o coo ler w it h t her ma l e nerg y sto r age ( T ES ) . T he y e mp lo yed a mat he mat ica l mo de l t o det er mine T E S capac it y and hydr o coo ler par a met er s, and t hen pr o ceeded wit h str uct ur al des ig n a nd t est ing. Resu lt s de mo nst r at ed r apid pr ecoo ling o f lit c his w it hin 15 minut es, hand ling o f 299 kg o f lit c his w it h o ne-t hir d T ES sto r age, and e ffe ct ive T E S capacit y w it h a n energ y e ff ic ie nc y r at io o f 2. Opt ima l p er fo r ma nce was ac hie ved w it h spec ific li t chi lo ad and spr a y f lo w r at e. Figu re 2. 2: S pr ay hydr o coo ler ( Repr int ed fr o m Huang, 2023) Fuku ya ma et a l. ( 2023) inve st igat ed t he opt ima l co nce nt r at io n o f c hit o sa n-wat er na no co mpo s it e ( CWN) fo r pr eser ving lit c hi fr u it s. Tr eat me nt s wit h 9% and 18% CWN s ig nif ica nt ly r educed we ig ht lo ss co mpar ed to t he co ntro l gr o up while ma int a ining qua lit y par a met er s such a s L\* va lue, pH, and tot al so lu ble so lid s ( T S S %) . S u mi et al. ( 2021) t r eat ed lit c hi fr u it s w it h var io us so lut io ns a nd eva luat ed t he ir qua lit y dur ing sto r age. Fr uit s tr eat ed wit h 1% calc iu m nit r at e and sto r ed at 4°C exhib it ed t he hig hest le ve ls o f asco r bic ac id, fr u it fir mnes s, and t he lo west acid it y. Mea nw hile, fr u it s t r eat ed wit h 1% ca lc iu m c hlo r ide a nd st o r ed at 4°C ma int a in ed hig h le ve ls o f tot al so lu ble so lid s, tot al

11 sugar, and s ig nif ic a nt ant ho cya nin co nt ent in t he pee l eve n a ft er 8 da ys o f st or age. T hese f ind ing s hig hlig ht t he pot ent ia l o f ca lc iu m nit r at e and ca lc iu m c hlo r id e tr eat me nt s in pr eser ving lit c hi fr u it qua lit y dur ing st o r age. Y. Xu et al. ( 2018) co nduct ed r esear ch o n a so lar pho to vo lt a ic-po wer ed ic e sto r age air co nd it io ning s yst e m. T he y t est ed t wo o per at io na l mo de ls t hro ugh exper ime nt s. T he r esu lt s ind icat ed t hat ice t her ma l st o r age co uld e ffe ct ive ly r ep lace a bat t er y ba nk fo r sto r ing so lar ener g y in t he fie ld o f d ist r ibut ed photo vo lt a ic r efr iger at io n. Ke y f ind ings fr o m t he exper ime nt s inc lude t hat , dur ing su nny da ys, t he ice co u ld fu lly r ep lace t he bat t er y ba nk in t he ener g y st or age pro cess fo r ice-ba sed a ir cond it io ning s yst ems dr ive n by d ist r ibut ed pho to vo lt a ic e ner g y. Add it io na ll y, t he aver age e ne r g y ut ilizat io n e ff ic ie nc y o f t he ic e t her ma l sto r age air co nd it io ning s yst e m in wo r k ing mo de was 0. 0525. Over t hr ee da ys o f exper ime nt s, fr o m 8 AM to 5 P M, t he aver age ice pr o duct io n was 52. 56 kg, and t he a ver age ice t hick nes s fo r med o n t he evapo r ato r was 51. 17 mm. T he s yst e m de mo nst r at ed aver age r efr iger at io n e ff ic ie nc ie s o f 79% and 69% . Dur ing t he nig ht coo ling supp ly ( fr o m 7:30 P M to 11:30 P M) , t he aver age co o ling supp ly e ff ic ie nc y was 75% . I n t he seco nd o per at io na l mo de, whic h invo lved co nt inuo us t est ing fo r 2 days, t he s yst e m's aver age e ner g y ut iliz at io n e ffic ie nc y w as 33. 7% , whic h was 5. 62 t ime s hig her t han t he e ff ic ie nc y o bser ved in t he fir st mo de. "

12 Chap t er-II I M ATERIALS AND M ETHO DS 3. 1. Concep t of th e S olar Powe red S t orage S yst em T he o ver all co ncept o f t he so lar-po wer ed sto rage s yst e m is illu st r at ed in F igur e 3. 1. Co mpr is ing t hr ee ke y unit s, na me ly a sto r age unit , a coo ling s yst e m, and a co nt ro ller unit , t his s yst e m a ims t o pro vide a n e ff ic ie nt so lut io n fo r pr eser ving lit chi fr u it s po st-har vest . T he co o ling unit wa s as se mb led w it h co mpo ne nt s inc lud ing a co o ling pad, co o ling fa n, pu mp, and t ank. I n o per at io n, hot air was dr awn int o t he coo ling pad while wat er fr o m t he t ank was c ir cu lat ed via a pu mp, ma int a in ing a co o ler t emper at ur e wit hin t he unit . T he co o ling fa n fac il it at ed t he co nver s io n o f ho t air to coo l a ir, whic h was t hen d ir ect ed int o t he sto r age unit . S o lar pane ls int egr at ed int o t he st r uct ur e's roof s er ved as t he pr imar y po wer so ur ce, har nes s ing so lar e nerg y to dr ive t he s yst e m. To r egu lat e and mo nit o r t he ent ir e pr o cess, a co nt ro ller unit equ ipped w it h se nso r s was e mp lo yed. T he d ime ns io ns o f t he co mp let e st or age st r uct ur e wer e st andar d ized t o a le ngt h o f 4 feet 6 inc he s, a he ig ht o f 5 feet , and a widt h o f 3 feet , ensur ing pr act ica lit y a nd sca la bil it y fo r imp le me nt at io n. Figu re 3. 1: Desig n a nd o ver a ll co ncept o f t he pro po sed so lar po wer ed evapo r at ive coo ling sto r age syst e m.

13 3. 2. M at erial s Used in t h e Research T he des ig n a nd co nst r uct io n o f a so lar-po wer ed sto r age syst e m nece ss it at e a d iver s e ar r a y o f mat er ia ls to asse mble var io us co mpo ne nt s, enco mpass ing t he so lar po wer syst e m, t he coo ling mec ha nis m, a nd co nt ro l feat ur es. Fo r t he fa br icat io n o f t he co o ling unit , es se nt ia l co mpo ne nt s suc h as a co o ling fa n, co o ling pad, a nd mo to r wer e ut iliz ed to ensur e e ff ic ie nt heat diss ipat io n and t e mper at ur e r egulat io n. Add it io na ll y, o t her mat er ia ls e sse nt ia l fo r t he asse mb ly a nd o per at io n of t he coo ling unit wer e car e fu ll y se lect ed and pr o cur ed. Cr it ica l t o t he fu nct io na lit y o f t he s yst e m wer e t he senso r s emp lo yed fo r envir o nme nt a l mo nit o r ing w it hin t he st o r age unit . Temp er at ur e and hu mid it y se nso r s wer e emp lo yed to t r ack var iat io ns in e nviro nme nt a l co nd it io ns, while a n et hyle ne se nso r was inco r por at ed to det ect et hyle ne gas le ve ls, a vit a l ind ic at or o f fr u it r ipe nin g and pot ent ia l spo ilage. A co mpr ehe ns ive inve nto r y det ailing a ll mat er ia ls ut ilized in t he des ig n a nd imp le me nt at io n o f t he so lar-po wer ed s mar t stor age s yst e m w as co mp iled. T his inve nt or y pr o vides a t r anspar ent and s yst e mat ic o ver view o f t he spec ificat io ns a nd quant it ies o f eac h co mpo ne nt , fac il it at ing r ep licat io n and fur t her r esear ch in t his fie ld. Tab le 3.1. List o f mat er ia ls wit h spec if ic at io ns fo r t he so lar-po wer ed sto r age syst e m. S l no Mat er ia ls S pec if icat io ns F igur e 1. S tr uct ur al c has s is Le ngt h 4 fe et 6-inc h, He ig ht 5 feet , widt h 3 feet 2. Coo ling pad ar r a nge me nt w it h upper co nt ainer and lo wer co nt ainer He ig ht 48-inc h, le ngt h 34 inc h, w idt h 3 inc h 3. Coo ling fa n Size 18 inc h

14 4. E xhaust fa n Mo de l E X- 06, I nput 220V, 50 Hz po wer : 28 W, s iz e 6 inc h 5. S o lar pane l Mo de l RS -M 150, Maximu m po wer 150 W, M inimu m po wer cur r ent 7. 42A 6. P u mp Vo lt age DC 12 V, Po wer 8W, H. Ma x 5m, F lo w 10 L/ min 7. C2H4 senso r Mo de l C2H4 - S M30, Measur e me nt r ange: 0~10 pp m, 0~100 ppm, 0~1000 pp m, Accur a c y: <+- 3% F. S 8. CO2 senso r S ize ( W) 40 mm× ( H) 36 mm × ( D) 11. 7 mm, we ig ht 12 g, Measur ing r ange 0~ 3000/5000 pp m, P o wer input DC 5V- 9V 9. Temper at ur e and hu mid it y se nso r Mo de l AM2315C, liv ing r oo m t emper at ur e 15. 6°C, L iving Roo m hu mid it y 63% 10. M icr o co nt ro ller Br and Ra sp ber r y p i, Mo de l 3577

15 11. Wif i Mo dule Mo de l E S P 8266 12. Tank He ig ht 5 m, le ngt h 26 m, Widt h 7m 13. S he lf le ngt h 3 feet , widt h 11 inc h 14. Re fr act o met er Accur a c y +- 0. 5 % 15. Adapt er Mo de l PA -1061-0, I NPUT 100-240 V ~ 50 -60, OUTP UT:12V-5. 0A 16. P enet r o met er Mo de l E N I S O 14488 17. Basket Widt h 11-inc h, Lengt h 15. 5-inc h, He ig ht 7.5 inc h 18. We ig ht Ba la nc e MODE L - JJ3000A, Capac it y 3000g

16 19. Batt er y Ho r sepo wer Mo del -215, E CO po wer mo de l-220 20. P H met er Br and JE NCO, Mo de l-6177M 21. S lide Ca liper Wiika ver nier ca liper 150 mm ( 6 inc h) , WA-VC 1150 s lid e Ca liper 22. P la ne s heet Le ngt h 4 fe et 6-inc h, w idt h 5 feet , Heig ht 3 feet 23. S o lar charge co nt r o ller Mo de l 2430 C Amp: 30A Vo lt : 12V/ 24V 24. Ju mp er w ir e Ma le to Ma le Ju mper Wir es 20 P in 20 c m a nd F e ma le t o Fe ma le Ju mper Wir e s 40 P in 30 cm 25. Co r k sheet Le ngt h 4 fe et 6-inc h, w idt h 5 feet , Heig ht 3 feet 26. Br ead bo ar d P last ic P ar t s Mat er ia ls ABS D ist r ibut io n Ho les. 200 a nd Ter mina l Ho le s 630 27. LCD D isp la y I C Chip P CF8574 I nput Vo lt age Ra nge ( VDC) 5

17 3. 3 Const ru ct ion of t h e S t orage S t ru ct u re T he sto r age str uct ur e was met icu lo u s ly co nst r uct ed wit hin t he eng ine er ing wo r ksho p lo cat ed in Ut taro n E ng ineer ing, D ina jpur, ut iliz ing a n ir o n fr a me fo r ro bust ness a nd dur abil it y. I t co mpr ise s t hr ee pr imar y se ct io ns: t he coo ler u nit , sto r age unit , and co ntro ller. T he co o ler unit was o ut fit t ed wit h t wo 18-inc h co o ling fa ns, a coo ling pad, mo to r, and a wat er co nt ainer to fac il it at e effect ive t e mper at ur e r egulat io n. Add it io na lly, a n e xhau st fa n was inst a lled o n t he s id e o f t he unit to enha nce a ir f lo w a nd ve nt ilat io n. Wit hin t he st o r age unit , an ir o n r ack was inco r porat ed to acco mmo dat e t he lit c hi fr u it s, w it h p la st ic basket s inst a lled w it hin t he r ack. E ach basket measur ed 15. 5 inc hes in le ngt h, 7. 5 inc he s in he ig ht , and 11 inc hes in w idt h, w it h a tot al o f 12 basket s d ist r ibut ed acro ss s ix r acks. Wit h eac h basket capable o f ho ld ing 150 lit c his, t he ent ir e sto r age unit co uld acco mmo d at e atot al o f 1800 lit c his. T he co nt ro ller s ect io n o f t he st r uct ur e was int egr at ed wit h var io us se nso r s to mo nit o r and ma int a in e nvir o nme nt a l co nd it io ns cr it ic a l fo r pr es er ving t he qua lit y o f t he st o r ed lit c hi fr u it s. I llu st r at io ns det ailing the co nst r uct io n o f t he sto rage st r uct ur e ar e pr esent ed in F igur e s 3. 2, 3. 3, 3. 4, and 3. 5. T he sto r age it se lf is co ver ed by a p la ne s he et and t hr ee la yer s o f p la ne she et, w it h a co r k sheet sandw ic hed bet wee n t he m to provide insu lat io n and pr ot ect io n. Figu re 3. 2: T he st r uct ur al c ha ss is Figu re 3. 3: T he str uct ur e co ver ed by p la ne s heet .

18 Mo r eo ver, t he backs ide o f t he str uct ur e ho uses t he coo ler unit , ensur ing e ff ic ie nt heat d is s ipat io n and t emp er at ur e co ntro l. Two exhaust fa ns wer e used o n bot h s ides o f t he sto r age st r uct ur e. Figu re 3. 4: T he ins id e par to f t he lit c hi sto r age st r uct ur e Figu re 3. 5: T he back s ide o f t he st r uct ur e 3. 4 S olar Powe r S yst e m Two so lar pa ne l w as used, and t he capac it y o f s ing le so lar pa ne l wa s 150 W at 15 V. T he s yst e m o per at ed us ing t wo 12V batt er ies w it h t he ass ist anc e o f a so lar charge inver t er co nt ro ller. 12V DC cur r ent was co nver t edto 220VAC. Whe n t he so lar pa ne l is e xpo sed to sunlig ht , t he photo vo lt a ic ( P V) cells w it hin t he pane l abso r b t he so lar energ y. S ubseque nt ly, t his abso r bed energ y induce s t he gener at io n o f e lect r ica l c harge s w it hin t he ce lls. T he se c harge s , in t ur n, r espo nd to an int er na l e lect r ica l f ie ld w it hin t he ce ll, t her eby facil it at ing t he flo w o f e le ct r ic it y. E lect r ic a l lo ad co mpr ises a l l t he elect r ic a l equ ip me nt used in t he lit c hi st o r age fac il it y, suc h as t he r efr ig er at io n unit , lig ht ing, and co nt ro l unit . Figu re 3. 6: So lar P o wer supp ly s yst e m.

19 3.5 Exp e rimen t a l P roced u re 3.5. 1. S am ple coll ecti on Fr es h lit c hi fr u it s wer e pr o cur ed fr o m Mas himp ur Far m lo cat ed in D ina jpur S adar. Upo n co llect io n, t he fr u it s u nder we nt pr e-coo ling u nde r t r ee shade t o mit igat e po st-har vest heat st r ess. S ubseque nt ly, t he fr u it s wer e met icu lo us ly so rt ed and gr aded, wit h o nly mat ur e and d is ease-fr e e Bo mba i lit c his be ing se lect ed fo r sto r age. 3.5. 2 S torage tech n iqu e T he se lect ed lit c hi s a mp le s wer e a llo cat ed to fo ur dist inct stor age s yst e ms t o eva luat e t he ir e ffect ive ne ss in pr eser ving fr u it qua lit y: ( a) Open ba mbo o basket : L it c his wer e sto r ed in t r adit io na l ba mbo o basket s to r epr esent a co mmo n sto r age met ho d used in lo ca l pr act ice and p la ced near ly t he evapo r at ive co o ling sto r age ( Figur e 3.7). Figu re 3. 7: Lit chi st o r ed in ba mbo o basket. ( b) Open plast ic basket : Lit c his wer e sto r ed in o pen p la st ic bask et s as an alt er nat ive sto r age appr o ach and placed near ly t he evapo r at ive cooling sto r age. T he a ir passed t hro ugh t he s yst e m ( F igur e 3. 8) . Figu re 3. 8: Lit chi st o r ed in o pen p last ic basket. ( c) Re fr iger at io n po ly bag: L it c his wer e sto r ed in r efr iger at io n po ly bags to s imu lat e co nt ro lled t emper at ur e stor age co nd it io ns ( F igur e 3. 9) .

20 Figu re 3. 9: Lit chi st o r ed in r e fr iger at io n po ly bag. ( d) E vapor at ive co o ling st or age s yst e m: Ano t her bat ch o f lit c his was sto r ed in t he de ve lo ped evapo r at ive co o ling sto r age syst e m des ig ned spec ific a ll y fo r sho r t-t er m st o r age. T his s yst e m was s it uat ed at gar den in t he o pen e nvir o nme nt, wher e t he lit c his wer e p laced o n t he s he lve s w it hin t he st r uct ur e ( F igur e 3. 10). I n evapo r at ive coo ling st or age syst e m was used 12 basket and s ing le basket acco mmat ed 50 L it chis. E ach st or age s yst e m acco mmo dat ed 50 lit c hi sa mp les, e nsur ing co ns ist enc y a nd co mpar a bil it y a cr o ss exper ime nt a l co nd it io ns. Figu re 3. 10: Lit chi st o r ed in de ve loped st o r age st ruct ur e.

21 3.6. Evalu at ion of t h e S t orage S yst ems T he co nd it io n o f t he lit c his in eac h st o r age s yst e m was s yst e mat ic a lly e va lu at ed b y mo nit o r ing var io us qua lit y par a met er s and mea sur ing lo sse s o ver t ime. 3.6. 1 Evalu ati on process T he as ses s me nt invo lved per io d ic e va luat io ns at 2-da y int er va ls t o tr ack cha nges a nd me asur e lo s ses in t he st o r ed lit chi sa mp le s. Dat a co llect io n was co nduct ed met ho dica ll y t o ensur e co mpr e he ns ive r eco r ding o f t he fo llo w ing qua lit y par a met er s: Temper at ur e: Reco r dedto mo nit o rt he t her ma l co nd it io ns a ffe ct ing fr u it st or age. Hu mid it y: Measur ed t o assess mo ist ur e le ve ls w it hin t he st o r age envir o nme nt . F ir mne ss: E va lu at ed as an ind icat o ro f fr u it t ext ur e and st r uct ur al int egr it y. pH:Ana lyzed t o under st and t he ac idit y le ve ls a ffec t ing fr u it qua lit y. Tot al S o lu ble S o lids ( T S S ) : Measur ed to det ermine t he fr u it 's sugar co nt ent and sweet nes s. CO2 and C2H4 Leve ls: Mo nit o r ed to gauge r esp ir at o r y act ivit y a nd et hyle ne pr o duct io n, inf lue nc ing fr u it r ipe ning a nd se nes ce nce. P hys io lo g ica l Lo ss in We ig ht ( P LW) : Quant if ied to assess t he nat ur a l mo ist ur e lo ss o f t he fr u it s dur ing st o r age. 3.6. 2 Data Coll ecti on Dat a o n t hese par a met er s was co llect ed d ilig e nt ly at each int er va l t o capt ur e cha nges o ver t he sto r age dur at io n a nd to fac il it at e co mp ar at ive a na lys is bet wee n d iffer e nt stor age s yst e ms. T his s yst e mat ic appr o ach e nsur ed r o bust eva luat io n o f t he e ff icac y o f eac h st o r age met ho d in ma int a in ing lit c hi qua lit y a nd min im iz ing lo ss es.

22 3.7 M on it orin g of Amb ient Condit ion s 3.7. 1 Sof tware setu p T he so ft war e set up fo r mo nit o r ing t he lit c hi st o r age co nd it io ns invo lved t he use o f spec if ic app licat io ns and pr o gr amming e nvir o nme nt s. Ardu ino I DE was inst a lled fo r pro gr ammin g t he micr o co nt ro ller s ( Ar du ino UNO R3) used in t he senso r no des. T hingS peak We b S er ver was ut ilized fo r sto r ing a nd a na lyz ing t he dat a co llect ed fr o m t he se nso r s dep lo yed in t he lit c hi st o r age st r uct ur e. T hingView App was use d fo r r ea l-t ime vis ua lizat io n o f t he lit c h i sto r age co nd it io ns, ena bling r e mo t e mo nit o r ing. Figu re 3. 10: S napsho t o f t he T hingS peak we bser ver

23 Figu re 3. 11: S naps hot o f dat a pro cess Figu re 3. 12: S naps hot o f Ar du ino P r o gr a m

24 3.7. 2 Hardware setu p T he har dwar e set up co mpr ised so phist icat ed co mpo nent s to ensur e accur at e dat a acquis it io n and r e mo t e mo nit o r ing capa bil it ies. I ns ide se nso r no de co mpo sed o f micr o co nt ro ller : ( Ar du ino Uno R3), senso r s ( DHT-22 ( humid it y a nd t emp er at ur e), CO2 senso r, C2H4 ( et hyle ne) se nso r ) , co mmu nicat io n Mo du le s ( S X1278 Lo Ra mo du le, E S P 8266 Wi-F i mo du le) , and P o wer S upp ly ( 9V batt er y) . Out s ide se nso r no de co mpo sed o f micr o co ntro ller ( Ar du ino Uno R3) , senso r s ( DHT-22 ( hu mid it y a nd t emper at ur e) , CO2 senso r, co mmu nic at io n Mo dules ( S X1278 Lo Ra mo du le) and po wer supp ly ( 9V bat t er y) . Figu re 3. 13: Har dwar e set upo f r ea l-t ime st or agemo nit o r ing s yst e m. 3.8 Dat a Acq u isit ion T he se nso r no des wer e st r at egic a lly inst a lled w it hin t he lit c hi st o r age st r uct ur e to mo nit o r cr it ica l e nvir o nme nt a l par a met er s esse nt ia l fo r pr eser ving fr u it qua lit y o f t e mper at ur e and hu mid it y se nso r was used fo r mo nit o r ing a mb ie nt co nd it io ns cr uc ia l fo r lit c hi sto r age. CO2 se nso r was used fo r mo nit o r ing car bo n d io xid e le ve ls ins ide t he sto r age co nd it io ns. C2H4 se nso r was e mp lo yed to det ectt he et hyle ne gas le ve ls. The dat a co llect ed by t he se nso r s wer e pro cessed by t he micr o co ntro ller s ( Ar du ino Uno R3) w it hin eac h se nso r no de. T he Ar du ino bo ar ds t rans mit t ed t he co lle ct ed dat a to t he c lo ud sto r age via t he E S P 8266 Wi-F i mo du le. Fr o m t he clo ud stor age, t he dat a was access ib le via t he T hingS pe ak app lic at io n, a llo w ing far mer s to r e mo t ely mo nit o r and ma nage t he ir lit c h i sto r age co nd it io ns in r ea l-t ime.

25 T his set up not o nly fac il it at ed e ffe ct ive mo nit o r ing o f sto r age par amet er s but also pro vid ed ins ig ht s to o pt imiz e sto r age co nd it io ns, t her eby e xt end ing t he s he lf life o f lit c his a nd r educ ing po st har ve st lo sses. F igur e 3. 14 illu st r at es t he co mpr ehe ns ive pr o cess o f dat a acqu is it io n and r e mo t e mo nit o r ing imp le me nt ed in t he pr o po sed syst e m. Figu re 3. 14: Blo ck d iagr a m o f dat a acquis it io n 3.9 Evalu at ion of Post-Harvest Qu alit y Para met ers I n t his st udy, se ver a l k e y par a met er s wer e asse sse d to eva lu at e t he qua lit y a nd phys io lo g ic a l cha ng es o f lit c hi fr u it s dur ing st o r age: Fr u it s ize mea sur e me nt : T he dia met er and he ig ht o f each lit c hi fr u it sa mp le wer e mea sur ed us ing s lide ca liper s. T he fr u it s ize was t hen ca lcu lat ed as t he pro duct o f d ia met er and he ig ht . Figu re 3. 15: Measur e me nt o f fr u it s ize. M ir cr ocontr olar Ar d uin ob oar d

26 We ig ht lo ss ( % ) : P er io d ic mea sur e me nt s o f lit c hi f ru it weig ht , inc lud ing any da maged fr u it s, wer e co nduct ed using a d ig it a l e lect r o nic ba la nc e. We ig ht lo ss was ca lcu lat ed as a per cent age o f t he o r ig ina l we ig ht us ing t he fo r mu la a s descr ibed by Kur u ba ( 2007) . % We ig ht lo ss = In i t i al wei ght of f rui t:g;FF i n al wei ght of f rui t (g)In i t i al wei ght of f rui t (g) × 100 F ir mne ss ( Kg/c m²) : T he fir mnes s o f t he fr u it was ass ess ed us ing a pe net ro met er ( HANDP I , China) , whic h mea sur ed t he fo r ce r equir edto penet r at et he fr u it 's sur face. Figu re 3. 16: Measur e me nt o f fir mnes s Tot al so lu ble so lid s ( % Br ix) : T he tot al so lu ble so lid s ( T S S) , an ind icat o r o f fr u it sweet nes s, wer e det er mined us ing a d ig it a l r e fr act o met er ( Hanna I nst r ume nt s, Ro ma nia) . Figu re 3. 17: Measur e me nt o fTot al so lu ble so lid

27 Co lo r ( L\*, a\*, and b\*) T he co lo r o f lit c hie fr u it s was asses sed us ing a Co lo r imet er ( Ko nica M ino lt a, CM 250d, Japa n) . T his met ho d quant if ies co lo r in t er ms o f t hr ee coor dinat es: L\* ( lig ht nes s) , a\* ( r ed-gr een a xis) , and b\* ( ye llo w-blu e axis) . L ig ht ne ss ( L\*) ind ic at es ho w lig ht o r dar k t he fr u it sur face is, w it h hig her va lues r epr ese nt ing lig ht er co lo r s. T he a\* va lue r epr es e nt s t he r ed-gr een spect r um, wher e po sit ive va lu es ind icat e r edness and negat ive va lues ind ic at e gr eenne ss. S imi lar ly, t he b\* va lue r epr ese nt s t he ye llo w-blue spect r u m, w it h po s it ive va lu es ind icat ing ye llo w nes s and negative va lues ind icat ing blu e nes s. Measur e me nt s wer e t aken o n bot h s ide s o f t he fr u it in t he equator ia l zo ne, w it h eac h mea sur e me nt r epeat edt wice to ensur e accur ac y ( F igur es 3. 18). Figu re 3. 18: Measur e me nt o f co lo r par amet er s Resp ir at io n a nd et hyle ne pr o duct io n: T he r esp ir at io n r at e o f t he sto r ed lit chi fr u it s, measur ed as t he a mo unt o f CO2 e vo lved, and et hyle ne pr o duct io n wer e mo nit o r ed. T his as ses s me nt was co nduct ed under differ e nt sto r age tr eatme nt s using a clo sed s yst e m appr o ach, fo llo w ing t he met ho do lo g y out lined by C a le b et al. ( 2012) .

28 Chap t er-IV Resu lt s an d Discu ssion 4. 1. M on it orin g of en viron men t a l p ara met e r 4. 1. 1. Temperature, humidit y condit ions, and carbon dioxide concentrati on Temper at ur e and hu mid it y s ig nif ica nt ly impa ct t he sto r age and s he lf life o f lit c his. E le vat ed t emper at ur es can incr eas e t he r esp ir at io n r at e o f t he lit c his, caus ing t he m t o decay a nd ha ve a r educed she lf life. T his st udy t r acked envir o nment a l co nd it io ns in t he se st o r age met ho ds (Figur e 4. 1) . T he hig he st ins id e hu mid it y w as 86. 36% , o ut side hu mid it y wa s 76. 48% , ins id e t emper at ur e was 27. 42°C, o ut sid e t emper at ur e was 31. 48° C. Figu re 4. 1: Chang ing in t e mper at ur e and hu mid it y wit h t ime. 26. 763827. 422927. 389727. 413826. 168926. 268783. 289783. 711384. 711784. 679686. 365886. 123630. 273530. 677130. 683930. 724131. 487931. 025975. 247276. 480776. 462775. 431873. 868973 . 87 56Da y-1Da y-2Da y-3Da y-4Da y-5Da y-6Te mpe r atur e and H umi di tyTi me dur ati onEvaporat ive Cooler ( Average)T em per a t ure(i n si de)Hum i di t y(i n si de)T em per a t ure(Out si de)Hum i di t y(Out si de)

29 0. 001. 002. 003. 004. 005. 006. 007. 002: 02: 00PM2: 05: 00PM2: 08: 00PM2: 11: 00PM2: 14: 00PM2: 17: 00PM2: 20: 00PM2: 23: 00PM2: 26: 00PM2: 29: 00PM2: 32: 00PM2: 35: 00PM2: 38: 00PM2: 41: 00PM2: 44: 00PM2: 47: 00PM2: 50: 00PM2: 53: 00PM2: 56: 00PM2: 59: 00PM3: 02: 00PM3: 05: 00PM3: 08: 00PM3: 11: 00PM3: 14: 00PM3: 17: 00PM3: 20: 00PM3: 23: 00PMC2H4Pr oduc ti on r ate(ppm)Ti meC2H4Concentratio n (B amboo B in) 4.1. 2 C2H4 con cen trati on in diff eren t storage condit ion 4.1.2. 1 Open a ir ( ba mbo o bin) I n t he Ba mbo o B in, t her e is a gr adua l incr eas e in t he co nc e nt r at io n o f C2H4. At cert ain po int s, t he co ncent r at io n exper ie nc es a decr ease, while at ot her t ime s it fluct uat es r ando mly. Figu re 4. 2: C2H4 Co nce nt r at io n ( Ba mbo o B in) 4.1. 2 .1 E vapo r at ive co o ler I n t he evapo r at ive co o ler, t he C2H4 co ncent r at io n gr adua lly incr ea ses s lig ht ly. At so me po int , t he co ncent r at io n decr ease s, while at ot her t imes it r e ma ins co nst ant.

30 0. 000. 501. 001. 502. 002. 503. 00C2H 4Pr oduc ti on r ate(ppm)Ti me C2 H4 Concentratio n (Evaporative Cooler) Figu re 4. 3: C2H4co ncent r at io n ( evapo r at ive co o ler ) 4.1.2. 1 Refr iger at io n I n t he co nt ext o f r efr iger at io n, it is impo rt ant to not e t hat t he co nce nt r at io n o f C2H4 fluct uat es w it hin t he r a nge o f 0. 80to 1. 20 demo nst r at ing a stead y var ia nce. Figu re 4. 4: C2H4 co ncent r at io n ( r e fr iger at io n) 0. 000. 200. 400. 600. 801. 001. 201. 404: 16: 00PM4: 17: 00PM4: 18: 00PM4: 19: 00PM4: 20: 00PM4: 21: 00PM4: 22: 00PM4: 23: 00PM4: 24: 00PM4: 25: 00PM4: 26: 00PM4: 27: 00PM4: 28: 00PM4: 29: 00PM4: 30: 00PM4: 31: 00PM4: 32: 00PM4: 33: 00PM4: 34: 00PM4: 35: 00PM4: 36: 00PM4: 37: 00PM4: 38: 00PM4: 39: 00PM4: 40: 00PM4: 41: 00PM4: 42: 00PM4: 43: 00PM4: 44: 00PM4: 45: 00PM4: 46: 00PM4: 47: 00PMC2H4Pr oduc ti on r ate(ppm)Ti meC2H4Concentratio n (Refrig eration)

31 4. 2 Post-harvest Qu alit y Evalu at ion P o st-har vest qua lit y par a met er s o f lit c hi wer e e va luat ed fr o m fo ur stor age co nd it io ns. Bo mba i lit c hi w as e va luat ed wit h fo ur sto r age syst e m, eac h stor age be ing co mpo sed o f t hr ee lit c his. 4. 2. 1 P h ysiol ogical loss inWeigh t (P LW) T he per cent age lo ss in we ig ht ( P LW) o f lit c hi fr u it s incr eased as t he stor age per io d advanc ed. A st at ist ica ll y s ig nif ica nt differ e nce was not ed amo ng t he var io us sto r age co nd it io ns. T he hig he st P LW wa s o bser ved in lit c hi fr u it s st o r ed at ambie nt co ndit io ns, fo llo w ed by t ho se sto r ed in o pen ba mbo o basket s. Wat er is t he pr im ar y co mpo ne nt o f fr u it s a nd veget ables, so min imiz ing it s lo ss is cr uc ia l fo r ma int a in ing t he ir po st har ve st qualit y at t r ibut es. Bro wning o f t he lit chi fr u it 's per icar p is c lo se ly linked t o dehydr at io n ( Mo lla 2017) . T he fr u it st or ed at r oo m t emper at ur e had lo wer r elat ive hu mid it y co mpar ed to t ho se sto r ed in r e fr iger at or s, r esu lt ing in a mo r e not icea ble incr eas e in P LW r ate and a r apid lo ss o f t he lit c hi fr u it 's br ig ht r ed co lo r. T her e fo r e, sto r ing lit c hi fr u it at roo m t e mper at ure is no t r eco mme nded due t o t he pot ent ia l fo r exces s ive we ig ht lo ss. Figu re 4. 5: We ig ht lo ss ( % ) o f L itc hi 4.2. 2 Firm n ess T he fir mnes s r ange o f evapo r at ive coo ling sto r age was 10 N to 15 N. T he hig he st fir mnes s va lue, 16. 03 N was o bser ved in t he o pen p la st ic ba sket co mpar ed t o ot her sto r age syst e ms. Cha ng ing F ir mne ss dur ing st o r age per io d is s ho wn in (Figur e-4. 6) 05101520253035Open Ba m bo ba sketOpen Pl a st i c ba sketRefr i ger a t orE va por a t i ve Cool i n gSt or a geWe i ghtl oss (% )Stor age c ondi ti onWeig ht loss(%)Da y-0Da y-2Da y-4Da y-6

32 02468101214161820Ope nBa mboba s ke tOpe nPl a s t i cba s ke tRe fr i ge r a t orEva por a t i ve Cool i ng St or a geF i r mne s sSt or age c ondi t i onFirmnes sDa y-0Da y-2Da y-4Da y-6 Figu re 4. 6: F ir mne ss o f L it c hi 4. 2. 3. Total solu ble soli ds ( T SS ) T he hig he st T SS va lue o bser ved was 17. 95% in t he r efr iger at or-sto r ed samp le s. T heT S S va lue fo r t he evapo r at ive co o ling st or age was near ly t he sa me, at 17%.Cha ng ingT S S dur ing sto r age per io d is s ho wn in (F igur e 4. 7) Figu re: 4. 7: Tot al S o lu ble So lids o f L it c hi 02468101214161820Open Ba m bo ba sketOpen Pl a st i cba sketRefr i ger a t orE va por a t i veCool i n g St or a geTSSStor age c ondi ti onTS SDa y-0Da y-2Da y-4Da y-6

33 4. 2. 4. Color (l\*a\*and b\*) Co lo r (L\*) : T he hig he st lig ht nes s (L\*) va lue r eco r ded was 49, o bser ved in t he r efr iger at or sto r age met ho d. T his sugg est s t hat r efr iger at io n e ffe ct ive ly pr eser ved t he lig ht nes s o f t he lit c hi fr u it s, like ly due t o r educed enz ymat ic br o wning a nd s lo wer degr adat io n pr o cesses at lo wer t emper at ur es. Figu re 4. 8: Co lo r (L\*) o f L it chi Co lo r (a\*) : I n t er ms o f r ednes s ( a\* va lue) , t he hig he st va lu e r eco r ded was 27. 39 in t he evapo r at ive coo ling st or age met ho d. T his ind icat es t hat t he evapo r at ive co o ling s yst e m wa s e ffect ive in ma int a in ing t he r ed pig me nt at io n o f t he lit c hi fr u it s. T he co ns ist ent hig h a\* va lue s suggest t hat t he co ntro lled e nvir o nme nt o f t he evapo r at ive coo ling s yst e m mit ig at ed t he degr adat io n o f ant ho c ya nins, whic h ar e r espo ns ib le fo r t he r edco lo r in lit c his. Open Ba m bo ba sketOpen Pl a st i cba sketRefr i ger a t orE va por a t i ve Col l i n gSt or a geCol or (L\*)Stor ag e c ondi ti onColor (L\* )Da y-0Da y-2Da y-4Da y-6

34 Figu re 4. 9: Co lo r (a\*) o f L it c hi Co lo r (b\*) : Fo r t he b\* va lu e, t he hig he st r eco r ded was 16. 33, a lso o bser ved in t he r e fr iger at o r sto r age. T his ind icat es a t endenc y to war ds a mo r e ye llo w pig me nt in t he r e fr iger at ed lit c his, whic h co uld be att r ibut edto t he pr eser vat io n o f car o t eno ids and o t her ye llo w p ig me nt s. 05101520253035Open Ba m bo ba sketOpen Pl a st i cba sketRefr i ger a t orE va por a t i veCool i n g St or a geCol or (a\*)Stor age c ondi ti onColor (a\*)Da y-0Da y-2Da y-4Da y-6

35 Figu re 4. 10: Co lo r (b\*) o f L it c hi Co mpar at ive ana lys is o f t he co lo r par amet er s across d iffer e nt stor age met ho ds sho ws dist inct adva nt ages fo r each met ho d. Refr iger at or sto rage e ffect ive ly ma int a ins lig ht nes s and ye llo w ne ss, like ly due t o t he st able lo w t e mper at ures t hat s lo w do wn o xidat ive a nd e nz ymat ic r eact io ns. On t he ot her ha nd, t he evapo r at ive co o ling sto r age exce ls in pr eser ving t he r ed co lo r, ind icat ing a fa vo r able envir o nme nt fo r ma in t aining a nt ho c ya n in st abil it y. Over a ll, t he evapo r at ive coo ling sto r age s yst e m demo nst r at es a s ig nif ica nt pot ent ia l fo r pr eser ving t he des ir a ble co lo r att r ibut es o f lit c hi fr u it s. B y ma int a ining a st able a nd co nt ro lle d envir o nme nt , it effect ive ly r edu ces t he r at e o f colo r degr adat io n co mpar ed to ot her sto r age met ho ds. 4. 3B en efit Cost Rat ioAnalysis T he co st-bene fit r at io ana lys is o f t he deve lo ped s t r uct ur e co ns id er ing a tot al capac it y 1800 lit c hi a nd a life spa n o f 20 year s is s ho wn in t able 4.1. T he lit c his wer e pur c hased at 350 Tk per 100 lit c his a ft er a 7 days st or age per io d, t he pr ice incr eased t o 450 Tk per 100 lit c hi. Fo r t he co st t he be ne fit r at io ( B:C) was o bser ved t o be 1. 20 T he hig he st co st-bene fit r at io o f 1. 25 was o bser ved o ver a per io d o f up to 20 year s w it ho ut co ns ider ing co nst r uct io n co st , ind icat ing t hat t he stor age str uct ur e is eco no mica ll y fe as ib le. 02468101214161820Open Ba m bo ba sketOpen Pl a st i cba sketRefr i ger a t orE va por a t i veCool i n g St or a geCol or (b\*)Stor age c ondi ti on Color (b\* )Da y-0Da y-2Da y-4Da y-6

36 Tab le 4. 1: B en efit cost rat io of t h e d evelop ed st ru ct u re Yea r In p u t cost Ou t p u t Cost 1 350×1800+24000 = 654000 450×1750 = 787500 2 350×1800 = 630000 450×1750 = 787500 3 350×1800 = 630000 450×1750 = 787500 4 350×1800 = 630000 450×1750 = 787500 5 350×1800 = 630000 450×1750 = 787500 6 350×1800 = 630000 450×1750 = 787500 7 350×1800 = 630000 450×1750 = 787500 8 350×1800 = 630000 450×1750 = 787500 9 350×1800 = 630000 450×1750 = 787500 10 350×1800 = 630000 450×1750 = 787500 11 350×1800 = 630000 450×1750 = 787500 12 350×1800 = 630000 450×1750 = 787500 13 350×1800 = 630000 450×1750 = 787500 14 350×1800 = 630000 450×1750 = 787500 15 350×1800 = 630000 450×1750 = 787500 16 350×1800 = 630000 450×1750 = 787500 17 350×1800 = 630000 450×1750 = 787500 18 350×1800 = 630000 450×1750 = 787500 19 350×1800 = 630000 450×1750 = 787500 20 350×1800 = 630000 450×1750 = 787500 Tot al 12624000 15750000 Co ns ider ing 50 lit c hi lo ss inc lud ing we ig ht lo ss, rott ing Bt = 15750000 ( Bene fit o ver t ime, t) Ct = 12624000 ( Bene fit o ver t ime, t) r = 16% ( disco unt r at e) BCR= Ã$P(1+N)PP0Ã%P(1+N)PP0

37 Fo r t he fir st year, t he be ne fit co st r at io was ca lcu la t ed as fo llo w s: BCR = Ã787500(1+0.16)7200Ã654000(1+0.16)7200 = 1.20 Over a 20 year s per io d, t he be ne f it co st r at io was- BCR = Ã15750000(1+0.16)7200Ã12624000(1+0.16)7200 = 1. 25 T his a na lys is de mo nst r at es t he eco no mic via bil it y o f t he st o r age st r uct ur e, o ffer ing a fa vo r able r et ur n o n inve st me nt bot h in t he s ho rt t er m and o ver t he lo ng t er m. Not ably, t he co st-bene fit r at io impr o ve s fr o m 1. 20 in t he fir st year to 1. 25 o ver a 20-year per io d, hig hlig ht ing t he su bst ant ia l eco no mic ad va nt ages and su st a ina bilit y o f t he st r uctur e in t he lo ng r un.

38 C hap te r-V Concl us i ons 5.0 Conclu sion A so lar-po wer ed evapo r at ive co o ling sto r age syst em w as de ve lo ped to ext end t he she lf li fe o f lit c hi fr u it s. T his s yst e m a ims t o addr ess t he s ignific a nt po st-har ve st lo ss es, impr o ve t he qua lit y o f sto r ed lit c his, a nd pr o vide a n eco-fr ie nd ly a nd co st-effect ive so lut io n fo r lit c h i pr eser vat io n in Ba ng la des h. T he find ing s fr o m t his st ud y de mo nst r at ed t hat t he so lar-po wer ed sto r age s yst e m e ffect ive l y ma int a ined fa vo r able co nd it io ns fo r lit c hi st o r age. T he s yst e m succes s fu ll y e xt end ed t he she lf life o f lit c his by ma int a in ing o pt ima l t e mper at ur e and hu mid it y le ve ls, t her eby r educ ing phys io lo g ica l w e ig ht lo ss ( P LW) a nd pr e ser ving f ir mne ss. T he st or ed lit c his r et a ined t he ir co lo r, sweet ness ( T S S ), and fir mne ss s ig nif ica nt ly bet t er t han t ho se sto r ed under t r adit io na l met ho ds, such as o pen ba mbo o o r pla st ic ba sket s. T he s yst e m ma naged et hyle ne co nce nt r at io ns e ffect ive ly by va lue, whic h is cr ucia l fo r s lo w ing do wn t he r ipe ning pr o cess and pr eve nt ing r ap id spo ilage. Fur t her mo r e, ut iliz ing so lar po wer made t he s yst e m e nerg y-e ffic ie nt and envir o nme nt a lly fr ie nd ly, o ffer ing a s ust aina ble a lt er nat ive fo r lit c hi far mer s and t r ader s. Over a ll, t his so lar-po wer ed evapo r at ive c ooling s yst e m ha s sho wn t o be an e ffic ie nt met ho d fo r sho rt-t er m sto r age o f lit c hi fr u it s, mit igat ing t he cha lle ng es o f r apid det er io r at io n and impr o ving mar ket abilit y. 5.1 Fu t u re Resea rch To fur t her enha nce t he per fo r ma nce and sca la bil it y o f t he so lar-po wer ed sto r age syst e m, t he fo llo w ing ar ea s ar e r eco mme nded fo r fut ur e r esearch: I nvest igatio n int o alt er nat ive coo ling met ho ds or mat er ia ls t hat co uld fur t her enha nc e t he e ffic ie nc y o f t he evapo r at ive co o ling s yst e m. E xp lo rat io n to sca le up t he sto rage syst e m fo r la rger quant it ie s o f lit c his a nd o t her per is ha ble fr u it s, e nsur ing pr act ica lit y fo r co mmer c ia l use. I mp le me ntat io n o f ad va nced I o T t echno lo g ies a nd auto mat io n w ill fur t her st r ea mlin e t he mo nit o r ing and co nt r o l o f sto r age co nd it io ns, r educ ing t he need fo r ma nua l int er ve nt io n.

39 Resear c h int o co mp le me nt ar y met ho ds t hat can ext end t he sto r age dur at io n be yo nd sho r t-t er m so lut io ns, such a s int egr at ing mo d if ied at mo spher e packag ing ( M AP ) w it h t he exist ing s yst e m. Co nduct a co mpr e he ns ive co st-bene fit a na lys is to eva luat e t he eco no mic via bil it y o f w ide spr ead ado pt io n o f t he so lar-po wer ed sto r ages yst e m a mo ng s ma ll-s ca le far mer s. B y addr es s ing t hese ar eas, fut ur e r esear ch can co ntr ibut e to t he deve lo p me nt o f mo r e adva nced, eff ic ie nt , and sust aina ble st orage solut io ns fo r lit c hi fr u it s, be ne f it ing bot h pr o ducer s and co nsu mer s. This so lar-po wer ed evapo r at ive coo ling st or age s yst e m o ffer s a pro mis ing so lut io n fo r impr o ving t he po st-har vest ma nage me nt o f lit c hi f r u it s. Co nt inued r ese ar ch a nd inno vat io n in t his fie ld ca n lead t o mo r e effect ive pr eser vat io n t echnique s, r educ ing po st-har ve st lo sse s, and enha nc ing t he o ver a ll qua lit y a nd a va ila bil it y o f lit chis in t he mar ket .

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43 Appe ndice s P yt hon c ode f or s e ns or data ac q uis iti on: h# inc lude " AM2315C. h" # inc lude <S P I . h> # inc lude <S D. h> AM2315C DHT ; co nst int CO2 P in =A0 ; // p in co nnect ed tot he senso r 's o ut put co nst int chipS e le ct = 4; f lo at nu mber 2, nu mber 3, nu mber 4; vo id set up( ) { S er ia l. beg in( 9600) ; // S t art ser ia l co mmu nicat io n w it hAr du ino I DE // Wir e. beg in( ) ; DHT. beg in( ) ; pinMo de( CO2P in, I NPUT ) ; S er ia l. pr int ln( " Wa it 90s. . . .. . ") ; dela y( 90000) ; /\* S er ia l. pr int ( "I nit ia liz ing S D car d. .. ") ; // see if t he car d is pr ese nt and can be init ia liz ed: if ( !S D. beg in( c hipS e lect ) ) { S er ia l. pr int ln( " Car d fa iled, o r not pr esent ") ; // do n't do anyt hing mo r e: while ( 1) ; } S er ia l. pr int ln( " car d init ia lized. ") ;\*/ } vo id lo o p( ) { CO2 pp m( ) ; Temper at ur e( ) ; Humid it y( ) ; /\*S tr ing dat aS tr ing= nu mber 2+", "+ nu mber 3+", " nu mber 4 ; F ile dat aF ile = S D.o pen( "dat a lo g.t xt ", FI LE \_WRI T E ) ; // if t he file is a va ila ble, wr it eto it : if ( dat aF ile) { dat aF ile. pr int ln( dat aSt r ing) ; dat aF ile. c lo se( ) ; // pr int to t he ser ia l po rt too : S er ia l. pr int ln( dat aS t r ing) ; } // if t he file is n't o pen, po p up an er ro r :

44 else { S er ia l. pr int ln( " er r o ro pening dat a lo g.t xt ") ; }\*/ dela y( 2000) ; } f lo at Temp er at ur e() { int st at us = DHT. r ead( ) ; flo at T =DHT. getTemper at ur e( ) ; S er ia l. pr int ( " I nTemper at ur e=") ; S er ia l. pr int ( T ) ; r et ur n( T ) ; } f lo at Humid it y( ) { int st at us = DHT. r ead() ; flo at H=DHT. get Humid it y( ) ; S er ia l. pr int ( " I n Hu mid it y=") ; S er ia l. pr int ln( H) ; r et ur n( H) ; } // CO2 in pp m f lo at CO2 ppm( ) { flo at vo lt age; // Var ia ble t o stor et he ana lo g vo lt age va lue flo at CO2Co ncent r at io n; // Var ia ble to sto r et he ca lcu lat ed CO2 co ncent r at io n int ana lo gVa lue = a na lo gRe ad( CO2 P in) ; // Co nver t t he ana lo g va lue t o vo lt age ( assu ming a 3V r efer e nce) vo lt age = ana lo gVa lue \* ( 3. 0 / 1023. 0) ; // Uset he map fu nct io n t o calcu lat e CO2 co ncent r at io n if ( vo lt age <= 1. 0) { CO2 Co ncent r at io n = map( a na lo gVa lue, 0, ( int ) (1. 0 \* 1023 / 3. 0) , 0, 1000) ; } else if ( vo lt age <= 2. 0) { CO2 Co ncent r at io n = map( a na lo gVa lue, ( int ) ( 1.0 \* 1023 / 3. 0), ( int ) ( 2. 0 \* 1023 / 3. 0) , 1000, 3000); } else

45 { CO2 Co ncent r at io n = map( a na lo gVa lue, ( int ) ( 2.0 \* 1023 / 3. 0), 1023, 3000, 5000) ; } // P r int t he CO2 co nce nt r at io n va lue to t he ser ia l mo nit o r S er ia l. pr int ( "CO2 Co nce nt r at io n: ") ; S er ia l. pr int ( CO2 Co nce nt r at io n) ; S er ia l. pr int ( " pp m") ; r et ur n( CO2 Co nce nt r at io n) ; } # inc lude < WiF i. h> # inc lude " secr et s. h" # inc lude "T hingS pe ak. h" // alw a ys inc lude ThingS peak header file a ft er ot her header file s and cust o m macr o s # inc lude <DHT 22. h> # inc lude " AM2315C. h" #de fine data 25 AM2315C DHT ; DHT 22 dht 22( dat a) ; co nst int CO2 P in = 34 ; // pin co nnect ed tot he sens o r 's o utput co nst int C2H4 P in=32 ; co nst flo at r ange = 600; // S enso r 's r ange in pp m char ss id[ ] = S E CRE T \_S SI D; // yo ur net wo r k S SI D ( na me) char pas s[ ] = SE CRE T\_PAS S ; // yo ur net wo r k passwo r d int ke yI nde x = 0; // yo ur net wo r k key I nd e x nu mber ( needed o nly fo r WE P ) WiF iC lie nt clie nt ; uns ig ned lo ng myC ha nne lNu mber = S E CRE T \_CH\_I D; co nst char \* myWr it e AP I Ke y = S E CRE T \_WRI T E \_AP I KE Y; // I nit ia lize o ur va lues int nu mber 1 = 0; int nu mber 2 = 0; int nu mber 3 = 0; int nu mber 4 = 0; int nu mber 5 = 0; int nu mber 6 = 0; co nst flo at VOLTAGE \_RE F = 3. 0; co nst int ADC\_ M AX = 1023; co nst flo at VOLTAGE \_1 = 1. 0; co nst flo at VOLTAGE \_2 = 2. 0;

46 co nst flo at VOLTAGE \_3 = 3. 0; co nst flo at CO2\_CONC\_1 = 1666. 7; co nst flo at CO2\_CONC\_2 = 3333. 3; co nst flo at CO2\_CONC\_3 = 5000. 0; S tr ing myS t at us = ""; vo id set up( ) { S er ia l. beg in( 115200) ; // I nit ia lize ser ia l Wir e. beg in( ) ; DHT. beg in( ) ; p inMo de( C2H4P in, I NPUT) ; // S et t he P WM p in as an input p inMo de( CO2P in, I NPUT ) ; while ( !S er ia l) { ; // wait fo r ser ia l po rt to co nnect . Needed fo r Leo nar do nat ive USB po rt o nly } WiF i. mo de( WI FI \_S TA) ; T hingS pe ak. beg in( c lie nt ) ; // I nit ia lize T hingS peak S er ia l. pr int ln( " Wa it 90s. . . .. . ") ; de la y(90000) ; } vo id lo o p( ) { // Co nnect o r r eco nnect to WiF i if( WiF i. st at us( ) !=WL\_ CONNE CT E D) { S er ia l. pr int ( " Att e mpt ing t o co nnect to S S I D: ") ; S er ia l. pr int ln( S E CRE T \_S S I D) ; while( WiF i. st at us( ) !=WL\_CONNE CT E D) { WiF i. beg in( s s id, pass) ; // Co nnect toWPA/ WPA2 net wo r k. Chang e t his line if u s ing o pen or WE P net wo r k S er ia l. pr int ( ". ") ; de la y( 5000) ; } S er ia l. pr int ln( "\nCo nnect ed. ") ; } nu mber 1 =C2H4 pp m( ) ; nu mber 2 =CO2 pp m ( ) ; nu mber 3 =I nTe mper at ur e( ) ; nu mber 4 =I nHu mid it y( ) ; nu mber 5 =OutTe mper at ur e( ) ; nu mber 6 =Out Humid it y( ) ;

47 // sett he fie ld s w it h t he va lu es T hingS pe ak. set F ie ld( 1, nu mber 1) ; T hingS pe ak. set F ie ld( 2, nu mber 2) ; T hingS pe ak. set F ie ld( 3, nu mber 3) ; T hingS pe ak. set F ie ld( 4, nu mber 4) ; T hingS pe ak. set F ie ld( 5, nu mber 3); T hingS pe ak. set F ie ld( 6, nu mber 4) ; // wr it eto t he T hingS peak c ha nne l int x = T hingS peak. wr it eF ie ld s( myC ha nne lNu mb er, myWr it e AP I Ke y) ; if( x == 200) { S er ia l. pr int ln( " C ha nne l updat e success fu l. ") ; } e lse{ S er ia l. pr int ln( "P r o ble m upd at ing c ha nne l. HTT P er ro r co de " + Str ing( x) ) ; } de la y( 2000) ; } f lo at C2H4 ppm( ) { uns ig ned lo ng dur at io nH ig h; // Dur at io n o f hig h pu ls e flo at C2H4Co nce nt r at io n; // Ca lcu lat ed CO2 co ncent r at io n // Measur e t he dur at io n o f t he hig h pu lse dur at io nH ig h = pu lseI n( C2H4 P in, HI GH) ; // Ca lcu lat et he CO2 co ncent r at io n us ing t he pro vided fo r mu la C2H4Co ncent r at io n = ( ( dur at io nH ig h - 2000. 0) /300000. 0) \* r ange; // P r int t he CO2 co nce nt r at io n va lue to t he ser ia l mo nit o r S er ia l. pr int ( "C2H4 Co nce nt r at io n: ") ; S er ia l. print ( C2H4 Co nce nt r at io n) ; S er ia l. pr int ( " pp m, ") ; r et ur n( C2H4Co ncent r at io n) ; } // Fo r Out s ide H imid it y f lo at Out Humid it y( ) { flo at h = dht 22. get Humid it y( ) ; S er ia l. pr int ( "Out Humid it y=") ; S er ia l. pr int ( h) ; r et ur n( h) ; }

48 // Fo r Out sideTe mper at ur e f lo at OutTemper at ur e( ) { flo at t = dht 22. getTemper at ur e( ) ; S er ia l. pr int ( " Out Temper at ur e=") ; S er ia l. pr int ( t ) ; r et ur n( t ) ; } // I ns ideTe mper at ur e f lo at I nTemper at ur e( ) { int st at us = DHT. r ead( ) ; flo at T =DHT. getTemper at ur e( ) ; S er ia l. pr int ( " I nTemper at ur e=") ; S er ia l. pr int ( T ) ; r et ur n( T ) ; } f lo at I nHu mid it y( ) { int st at us = DHT. r ead() ; flo at H=DHT. get Humid it y( ) ; S er ia l. pr int ( " I n Hu mid it y=") ; S er ia l. pr int ln( H) ; r et ur n( H) ; } // CO2 in pp m f lo at CO2 ppm( ) { int ana lo g Va lue = ana lo g Read( CO2P in) ; flo at CO2 Co ncent r at io n = r ead CO2 Co nce nt r at io n ( ana lo gVa lue) ; // P r int t he CO2 co nce nt r at io n va lue to t he ser ia l mo nit o r S er ia l. pr int ( "CO2 Co nce nt r at io n: ") ; S er ia l. pr int ( CO2 Co nce nt r at io n) ; S er ia l. pr int ln( " pp m") ; r et ur n( CO2 Co nce nt r at io n) ; } f lo at r ead CO2 Co nce nt r at io n( int ana lo gVa lue) { flo at vo lt age = ana lo gVa lu e \* ( VOLTAGE \_RE F /AD C\_M AX) ; flo at CO2Co ncent r at io n;

49 if ( vo lt age <=VOLTAGE \_1) { CO2 Co ncent r at io n = ana lo g Va lue \* ( CO2\_CONC\_1 / ( ADC\_M AX \*VOLTAGE \_1 / VOLTAGE \_RE F) ) ; } else if ( vo lt age <=VOLTAGE \_2) { CO2Co ncent r at io n = CO2\_CONC\_1 + ( ana lo g Va lue - ( VOLTAGE \_1 \*AD C\_M AX / VOLTAGE \_RE F) ) \* ( ( CO2\_CONC\_2 - CO2\_CONC\_1) /( ADC\_ M AX \* ( VOLTAGE \_2 - VOLTAGE \_1) /VOLTAGE \_RE F) ) ; } else if ( vo lt age <=VOLTAGE \_3) { co 2Co ncent r at io n = CO2\_CON C\_2 + ( ana lo gVa lue - ( VOLTAGE \_2 \*AD C\_M AX / VOLTAGE \_RE F) ) \* ( ( CO2\_CONC\_3 - CO2\_CONC\_2) /( ADC\_ M AX \* ( VOLTAGE \_RE F - VOLTAGE \_2) /VOLTAGE \_RE F) ) ; } else { CO2 Co nce nt r at io n = 0; } r et ur n CO2 Co nce nt r at io n; }

50 Appe d ni x-2 Table 1: C ha ng i ng te mpe r at ure , humi dit y, CO2 and C2H4 Da y T e mper at ur e ( ins ide) Hu mid it y ( ins ide) T e mper at ur e ( Out side) Hu mid it y ( Out side) CO2 ( pp m) Da y-1 26. 7638 83. 2897 30. 2735 75. 2472 472. 706 Da y-2 27. 4229 83. 711 30. 6771 76. 4807 468. 6016 Da y-3 27. 3897 84. 7117 30. 6839 76. 4627 479. 3681 Da y-4 27. 4138 84. 6796 30. 7241 75. 4318 481. 1683 Da y-5 26. 1689 86. 3658 31. 4879 73. 3689 488. 3625 Da y-6 26. 2687 86. 1236 31. 0259 73. 8756 478. 7639

51 Table 2: C ha ng i ng e t hyle ne c onc e ntr ati o n

52 Table 3: P hys i ol ogical l os s i n we ig ht (%) Da y Open Ba mbo ba sket Open P last ic ba sket Re fr iger at or E vapo r at ive Coo ling S tor age Da y-0 0 0 0 0 Da y-2 12. 96 7. 47 6. 69 15. 66 Da y-4 7. 98 8. 38 10. 39 20. 04 Da y-6 28. 37 19. 91 19. 53 24. 29 S t d dev 11. 95310106 8. 220685292 8. 14567523 10. 6009634 Table 4: C ha nge i nT S S d ur i ng s t or age p e r iod Da y Open Ba mbo ba sket Open P last ic ba sket Re fr iger at or E vapo r at ive Coo ling S tor age Da y-0 17. 9 15. 25 16 17 Da y-2 15. 35 16. 69 13. 6 17. 49 Da y-4 16. 54 17. 35 17. 95 17. 38 Da y-6 14. 86 15. 86 16. 53 16. 82 st d dev 1. 356229455 0. 921968004 1. 81124267 0. 315105802 Table 5: C ha nge i n F irm ne s s dur i ng s t or age pe r iod Da y Open Ba mbo ba sket Open P last ic ba sket Re fr iger at or E vapo r at ive Coo ling S tor age Da y-0 11. 5 10. 5 10. 3 10. 56 Da y-2 13. 96 15. 56 11. 5 15. 1 Da y-4 14. 43 16. 03 11. 56 13. 73 Da y-6 15. 83 16. 4 12. 66 14. 51 st d dev 1. 804235757 2. 769745777 0. 96420952 2. 0227127 Table 6: C ha nge i n c ol or (\*L) d ur i ng s t or age pe r iod Da y Open Ba mbo ba sket Open P last ic ba sket Re fr iger at or E vapo r at ive Coo ling S tor age Da y-0 40. 44 42. 39 41. 14 42. 57 Da y-2 42. 76 43. 69 47 44. 09 Da y-4 38 41. 33 49 41. 77 Da y-6 38 39. 66 47 41. 77 st d dev 2. 284089899 1. 704550283 3. 39679751 1. 093739762

53 Table-07: C ha nge i n c ol or (\*a) d ur i ng s t or age pe r i od Da y Open Ba mbo ba sket Open P last ic ba sket Re fr iger at or E vapo r at ive Coo ling S tor age Da y-0 18. 23 23. 64 17. 79 27. 39 Da y-2 11. 67 16. 69 11 20. 6 Da y-4 15. 66 15. 33 15. 66 15. 66 Da y-6 9. 66 9. 52 19. 33 14. 66 st d dev 3. 862680416 5. 800485612 3. 62383315 5. 819773048 Table-08: C ha nge i n c ol or (\*b) d ur i ng s t or age pe r i od Da y Open Ba mbo ba sket Open P last ic ba sket Re fr iger at or E vapo r at ive Coo ling S tor age Da y-0 12. 58 13. 26 13. 58 13. 9 Da y-2 12. 16 12. 8 15. 16 13. 51 Da y-4 11 11. 66 16. 33 9. 88 Da y-6 8 9 13. 66 9. 88 st d dev 2. 067615374 1. 909066089 1. 3169757 2. 214096881 Table-09: B e ne f it c os t r ati o a nalys is S l No. M at erials Na me M at erials Cost 01 Mat er ia ls a nd t echnic ia n co st 23500 02 Co lo r 500 Tot al 24000